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Managing Swine Manure in Double-Crop Soybean

Donald Joseph Graper
Purdue University

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Is approved by the final examining committee:

Dr. Shaun N. Casteel

Dr. James J. Camberato

Dr. Brad C. Joern

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Approved by Major Professor(s): Dr. Shaun N. Casteel

Approved by: Dr. Joseph Anderson 06/25/2014

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ABSTRACT

Graper, Donald Joseph. M.S., Purdue University, August 2014. Managing Swine Manure in Double-Crop Soybean. Major Professor: Shaun N. Casteel.

Animal production, especially swine (*Sus scrofa domesticus*) and poultry, has increased in the United States prompting the need to manage the larger volume of manure beyond land applications to supply nitrogen (N) for corn (*Zea mays*) production. Applying swine manure to soybean (*Glycine max*) has been shown to increase grain yield due to N supply. The goal of this research was to determine if swine manure applications to double-crop soybean following wheat can limit manure N loading to the soil by extending management options, increase soybean biomass and grain production, and increase N removal rates. Manure N availability to soybean and potential manure N loss were also to be determined. Four field-scale trials were initiated in 2012 near Russiaville, IN and Farmland, IN and in 2013 near Farmersburg, IN and Fort Branch, IN. Three rates of swine manure were applied that ranged from 116 to 599 kg N ha^{-1} depending on location. Fertilizer UAN was also applied at 168, 336, and 504 kg N ha^{-1}, and an untreated control (UTC) was included to total seven treatments. Biomass and nutrient accumulations were determined with plant samples at full bloom (R2) and full seed (R6), and grain subsamples at harvest. Soil N was determined for the 0 to 30 and 30 to 60 cm depths at

R2 and post-harvest, and soils were incubated at 25˚C and -0.33 bar water content for zero, four, eight, and sixteen (2012 only) weeks. Swine manure application increased soybean grain yield in conjunction with increased application rates in 2012 at Russiaville. This increase of yield was preceded by increased biomass accumulation at R2, but N application generally did not affect biomass accumulation at R6. All treatments supplied more N in the top 60 cm of soil after harvest compared to the UTC. In 2013, effects of swine manure application to soybean were negligible to negative. At Farmersburg, grain yield was negatively affected by manure application, and significant amounts of soil N were present after harvest in the manure-amended plots. At Fort Branch, biomass, grain yield, grain N removal, and post-harvest soil N were not affected by swine manure application suggesting less benefit from swine manure in a high yield environment with adequate moisture. Manure and UAN increased soil N levels compared to the UTC at sampling times (wk 0), but generally did not affect N release. Differences in N levels among treatments stayed constant throughout incubation indicating that mineralization rates were similar across treatments. Additional N from swine manure application was present throughout the growing season, including post-harvest if conditions were dry or the yield environment was low. This presented a potential for N loss through nitrate leaching during the winter if N was not accumulated in the soybean crop, removed by grain, or lost during the season. Overall, manure application to double-crop soybean can be a sound manure management option if it can be executed with minimal soil disturbance, and it is especially beneficial for those producers that need to free up manure storage space.

CHAPTER 1. REVIEW OF LITERATURE

1.1 Introduction

The US grew and harvested 30.7 million ha of soybean (*Glycine max*) valued at $41.8 billion in 2013 (USDA-NASS, 2014). Over time the production of swine (*Sus scrofa domesticus*) in the US increased to nearly 14.6 million t produced in 2012 (USDA-NASS, 2014). The concentrated areas of swine production, and subsequently, the large amount of manure generated has prompted research to determine non-traditional, efficient uses for swine manure to produce food, feed, fiber, and fuel.

1.2 Soybean History

1.2.1 Origin of Species

The cultivated soybean is widely believed to have originated somewhere in China about 3000 to 4000 years ago (Qiu and Chang, 2010). In 1765, soybean made its entrance into the US when Samuel Bowen asked Henry Yonge, the Surveyor-General of Georgia, to plant some seed that he had brought from China. Bowen produced soy sauce and many other products and was awarded with several recognitions for his accomplishments with the soybean. Five years after Samuel Bowen's introduction of the soybean, Benjamin Franklin sent seeds from England to a friend near Philadelphia and described them as “dry green peas”. It is believed that the seeds were soybean and they were grown in the receiver’s garden (Hymowitz and Harlan, 1983).

1.2.2 US Soybean Production

Worldwide soybean production increased 4.6% each year from 1961 to 2007, and it is expected to keep increasing at a rate of 2.2% annually in the foreseeable future. Soybean production is concentrated in five countries that produce 92% of the global supply: US, Brazil, Argentina, China, and India (Goldsmith and Masuda, 2009). The US has been the leading soybean producer across the world with 37% of the total supply. That number has dropped from 50% in the 1980s due to increased production in Brazil and Argentina. The area of soybean harvested worldwide increased fourfold from the 1960s to 2007, but the global share of area harvested held by the US dropped from 49% to 32% (Goldsmith and Masuda, 2009). The other factor that plays into total production is yield. Global average soybean yield has continued to rise since the 1960s to its current level of 2.3 t ha^{-1} (Goldsmith and Masuda, 2009).

Within the US, the upper Midwest grows more than 80% of the soybean (USDA-ERS, 2014). Soybean production is concentrated in the Midwestern states of Illinois, Iowa, Minnesota, Missouri, and Indiana; 3.8, 3.7, 2.7, 2.2, and 2.1 million ha in 2013, respectively (USDA-NASS, 2014).

1.3 Swine History

1.3.1 Origin of Species

Darwin suggested that swine was domesticated in Europe and Asia, and it is widely believed today that swine were domesticated about 9000 years ago from the Eurasian Wild Boar. A Swedish, DNA sequencing study confirmed Darwin's theory of dual domestication of swine (Giuffra et al., 2000). Domesticated swine were brought to the Americas sometime after 1450 by explorers or colonizers on slow moving ships, and it is believed that the ancestors were mainly from western Europe (Bennett, 1970).

1.3.2 US Swine Production

The US ranks second in global swine production behind China (Quick Facts NPB, 2012), producing 14.6 million t in 2012 (USDA-NASS, 2014). Swine production in the US has doubled since the 1970s (Quick Facts NPB, 2012) and is concentrated in the Midwestern states and North Carolina. Iowa, North Carolina, Minnesota, and Illinois account for over 60% of the US swine production, and Indiana ranks fifth in the US (Plain, 2008). Swine production in the US took a major turn in the mid-1990s towards fewer and larger farms, which compounded the concentration of producers within geographies. In 1993, the number of swine operations that marketed more than 4000 hogs annually was only 33% of the total number of producers. That number increased to 82% by 2007 (Plain, 2008). With increased swine production and concentration of production in the US, manure management limitations have arisen. The top soybean and swine producing states intersect, so swine manure application to soybean is a practical management option.

1.4 Soybean Growth and Development

1.4.1 Planting Date Effects

1.4.1.1 Yield

Planting date of full-season soybean in the Midwest has been pushed earlier due to generally higher yields. Longer vegetative and reproductive periods were primary sources of this yield improvement (Chen and Wiatrak, 2010). Other countries, such as Iran, have noted this planting date effect on yield (Moosavi et al., 2011). Planting full-season soybean in late April to early May maximizes soybean yield in Indiana (Robinson et al., 2009). An analysis of planting date studies described a rapid decline in yield when soybean was planted after May 30 in the Midwest (Egli and Cornelius, 2009). A Kentucky study using the SOYGRO model reported that once planting dates moved into mid-June, the decrease in soybean yield was 1.9% d^{-1} (Egli and Bruening, 1992).

Many growers in the Midwest and the southern US raise wheat (*Triticum aestivum*) and soybean in a double-crop system to increase profitability. In Mississippi, net returns of a wheat and soybean double-crop system were \$86 to \$571 ha^{-1} higher than those of early planted, full-season soybean in 2001, 2002, and 2004 (Kyei-Boahen and Zhang, 2006). Another study involving double-crop soybean and wheat in Oklahoma stated, “Double-cropping resulted in more total grain production and effective use of annual precipitation, its distribution, and soil stored water when compared to mono-cropping wheat and soybeans" (Crabtree and Rupp, 1980). Although double-cropping may be more profitable, it is widely known that soybean yields decrease as planting date is delayed. These lower yields may be due to moisture stress later in the season, heat stress, or photoperiod (Hu and Wiatrak, 2012). In the Mississippi study, the yields of the double-crop soybean were 258 to 1694 kg ha^{-1} lower than those yields of the full-season soybean (Kyei-Boahen and Zhang, 2006). Other studies in the mid-south demonstrated the reduction in yield potential of soybean as planting was delayed from April to July as the later dates relate to double-crop soybean yields (Bruns, 2011; Pfeiffer, 2000; Weaver et al., 1991).

1.4.1.2 <u>Growth and Biomass</u>

In Alabama, the height of soybean was lowered as planting date was delayed by one month (Weaver et al., 1991). In Florida, May planting produced 40% taller plants than July planting (Parvez et al., 1989). A Kentucky study reported that plant height and yield in a double-crop system were not consistently correlated, suggesting that taller plants did not translate into greater soybean yield (Pfeiffer, 2000). Height may not always directly relate to biomass production due to branching or plant population, but in the southern Pampas of Argentina, double-cropped soybean had less harvest biomass, grain yield, and individual seed weight than full-season soybean (Calviño et al., 2003). In India, delayed planting from mid-June to late July reduced pod number per plant, plant height, number of branches, and time from planting to flowering and maturity, which resulted in lower grain yield (Bhatia et al., 1999). Other work in Wisconsin, where double-cropping soybean after wheat is not possible, showed no relation between early and late May planting dates and plant height (Pedersen and Lauer, 2004).

1.4.1.3 <u>Grain Composition</u>

Grain composition of soybean can change based on planting date, but the changes are not consistent (Bastidas et al., 2008; Bellaloui et al., 2011; Hu and Wiatrak, 2012). In Argentina, lower grain oil concentration was positively related to later planting dates, while protein concentration was not affected (Caviglia et al., 2011). Kumar et al. (2006) also noted this effect in India. Lower oil concentrations were associated with later plantings in the Southeastern US, and the researchers suggested the source was cooler temperatures during seed fill (Kane et al., 1997). In Mississippi, later planted soybean had lower oil content and increased protein content compared to timely planted soybean (Bellaloui et al., 2011). A study in India concluded that delayed planting of soybean reduced protein and oil content of the grain (Billore et al., 2000), which is abnormal as protein and oil content typically change inversely. Delayed plantings in Pakistan also lowered protein and oil, and those researchers postulated that smaller seeds resulted in less protein (Muhammad et al., 2009). In Nebraska, soybean seed oil content generally decreased as planting date moved from early May to mid-June and protein content increased or decreased depending on the year (Bastidas et al., 2008). In Indiana, seed oil content decreased as planting date moved from late March to early June, and protein content either did not change or increased depending on the year (Robinson et al., 2009).

1.4.2 Soybean Nitrogen

1.4.2.1 Nitrogen Requirements and Uptake

Although soybean nitrogen (N) requirements are often ignored due to biological N fixation (BNF), soybean requires a large amount of N to support above ground biomass and to produce seed that is high in protein (Salvagiotti et al., 2008). Soybean required 29 mg N per g of photosynthate, which was the highest of all 24 crops that were evaluated including lentil (*Lens culinaris*), cowpea (*Vigna sinensis*), pea (*Pisum sativum*), and mung bean (*Phaseolus aureus*) (Sinclair and de Wit, 1975). Soybean maximizes daily N uptake at 4.5 kg N ha^{-1} d^{-1} between the R2 and R6 growth stages, and the maximum amount of N taken up by soybean occurs just before R7 (Hanway and Weber, 1971). On average, soybean takes up 219 kg N ha^{-1}, but can take up as much as 485 kg N ha^{-1} (Salvagiotti et al., 2008). Soybean can assimilate nitrate (NO_3^-), ammonium (NH_4^+), ammonia (NH_3), or urea ($CO(NH_2)_2$) (Polacco, 1976; Tolley-Henry and Raper, 1986). Soybean also reduces N_2 to NH_3 through BNF, though at a higher energy cost than soil NO_3^- uptake. Nitrate fed soybean retained 8 to 13% more photosynthate than soybean relying solely on N_2 fixation (Finke et al., 1982; Ryle et al., 1979).

1.4.2.2 Nitrogen Sources

Soybean receives most of its N from the soil and BNF. Biological N fixation contributed 84% of N taken up by inoculated soybean, but contributed as little as 44% when 200 kg N ha^{-1} was applied to non-inoculated soybean (Hungria et al., 2006). Soybean was grown in outdoor hydroponic gravel culture with varying rates of NO_3^-

supplied, and the highest yields (15 g seed plant^{-1}) were obtained on those plants that utilized both BNF and available NO_3^-. Maximum yields were lower at the time of the study than they are today, but 200 kg N ha^{-1} maximized grain yield (Harper, 1974). Organic matter is the main source of N from the soil to the plant, and residual N can also be crop-available due to over-fertilization or low crop removal. The process by which N is converted from an organic form to an inorganic form (NH_4^+ or NH_3) is termed mineralization. Mineralization of organic matter can produce about 22 kg N ha^{-1} yr^{-1} for every 1% organic matter in the soil (Havlin et al., 1975). The plant can then take up the NH_4^+ form or wait and take up the NO_3^- form after nitrification has occurred. Nitrification occurs because of two important bacteria in soil: *Nitrosomonas* and *Nitrobacter,* which convert NH_4^+ to nitrite (NO_2^-) and then NO_2^- to NO_3^-, respectively (Havlin et al., 1975).

1.4.2.3 **Biological Nitrogen Fixation**

Biological N fixation was discovered in pea plants in 1888 by Hellriegel and Wilfarth (Burris, 1998; Galloway and Cowling, 2002). At that time, BNF produced about 15 Tg N yr^{-1} globally, which accounted for nearly all the N used in food production (Galloway and Cowling, 2002; Smil, 1999). However in 1990, the Haber-Bosch process of ammonia production supplied more than double the N worldwide (95 Tg N yr^{-1}) compared to BNF (40 Tg N yr^{-1}) (Galloway et al., 1995; Smil, 1999).

Biological N fixation was discovered in soybean in the US in 1893 by W. P. Brooks (Hymowitz, 1990) and has accounted for 58% (IQR of 46 to 74%) of the total N accumulation in soybean production studies worldwide over the last 40 years (Salvagiotti et al., 2008). It was not until the early 1900's that soybean was inoculated with *R. japonicum* and variations in nodulation responses were noted among soybean genotypes (Voorhees, 1915). Soybean roots are infected immediately following seedling emergence by a soil rhizobium called *Bradyrhizobium japonicum* which initiates a symbiotic relationship 20 to 30 days after planting (Hardy et al., 1971). This relationship converts N_2 to NH_3 for the soybean plant and provides the rhizobium with energy (8.5 ATP per N atom reduced) and carbon (8g C g^{-1} N) (Gutschick, 1981). Maximum N fixation rate in nodulating soybean occurs from initial bloom through mid-pod fill stage with over 90% of total N fixed after flowering (Harper and Hageman, 1972).

Biological N fixation can supply as much as 300 kg N ha^{-1} to soybean biomass and grain in a single growing season (Bezdicek et al., 1978), but is influenced by several factors including: salt or drought stress, acidity, available soil N, and genetic compatibility of the partners (Keyser and Li, 1992; Zahran, 1999).

Inoculation of soybean has been studied with mixed results. Liquid inoculant increased soybean nodulation in high-yielding (4.7 Mg ha^{-1}) environments where soybean had not previously been grown (Revellin et al., 2000), but sterile-peat inoculant did not increase the proportion of N derived from fixation where soybean had been grown previously (Hungria et al., 2006). Generally, inoculants were ineffective at increasing yield if soybean had been grown at a location in the past. In a 71 site-year, multi-state study involving 51 different inoculation products, inoculation did not affect yield as compared to the untreated control at 63 site-years (De Bruin et al., 2010).

1.4.2.4 Nitrogen Accumulation

Soybean grain yield is positively correlated with N accumulation in above ground biomass (Cregan and Yaklich, 1986; Lathwell and Evans, 1951). By looking at 108 studies that were conducted all over the world from 1966 to 2006, it was concluded that soybean grain yield increased linearly 12.7 kg for every 1 kg of N accumulated in above ground biomass. Soybean yielding 0.58 to 5.89 Mg ha^{-1} will accumulate 44 to 485 kg N ha^{-1} in grain and biomass (Salvagiotti et al., 2008). In Iowa, 75 to 80% of the N accumulated in the soybean plant occurred between R2 (full bloom) and R6 (full seed) at a rate of 4.5 kg N ha^{-1} d^{-1}, and the nodulated soybean with no supplemental N accumulated 244 kg N ha^{-1} in biomass and grain. Soybean partitioned 24% of the total N accumulated to fallen leaves and petioles, 8% to mature pods and stems, and 68% was removed by grain (Hanway and Weber, 1971).

Grain N concentration averaged 6.34% over 108 studies with 122 to 184 kg N ha^{-1} removed in the grain of the inner quartile range (Salvagiotti et al., 2008). Vegetative biomass (leaves and stems) at growth stage R7 averaged only 1.22% N content, suggesting a large amount of the N was being remobilized to the seeds. Nitrogen harvest index (NHI) is the amount of N in the grain divided by the total amount of N in the grain and stover, and NHI averaged 0.73 in the review of N in soybean (Salvagiotti et al., 2008). In Illinois, NHI was positively correlated ($r = 0.57$) with seed yield (Jeppson et al., 1978). A study conducted in Iowa found that about half of the N in the mature seeds came from soil and nodules during seed development. The other half was redistributed from other parts of the plant after R4 (Hanway and Weber, 1971), which was supported by more recent studies (Jeppson et al., 1978; Salvagiotti et al., 2008).

1.4.3 Effects of Supplemental Nitrogen on Soybean

1.4.3.1 Yield

Yield of soybean is not consistently increased by supplemental N applications. In a review of 108 studies between 1966 and 2006, a positive yield response to N application occurred in half the studies and yield increase averaged 520 kg ha^{-1} (Salvagiotti et al., 2008). In Minnesota, supplemental N on soybean increased seed yield, suggesting that BNF cannot supply enough N to maximize yield (Ham et al., 1975). In Japan, soybean grain yield increased from 4800 kg ha^{-1} to 5920 kg ha^{-1} when 116 kg N ha^{-1} was applied pre-plant to a depth of 20 cm (Takahashi et al., 1992). Field studies in Kentucky reported increased soybean yield (+32%) from 168 kg N ha^{-1} applied at ~R1 or ~R3, but no response from combined applications was observed due to increased lodging (Brevedan et al., 1978). In a multi-state Midwest study, yield of modern varieties increased 20% when 560 kg N ha^{-1} was split applied (40% at planting, 60% at V5) to maturity group 3 soybean, but the same application did not affect yield of maturity group 2 soybean (Wilson et al., 2014). In Brazil, 200 kg N ha^{-1} split applied (50% at planting, 50% at R2) reduced BNF contribution to soybean by 40% and produced no additional soybean grain (Hungria et al., 2006). Averaged over three environments in Virginia, UAN applied at planting or R1 at a rate of 56 kg N ha^{-1} did not affect double-crop soybean yield. Application at R1 decreased yield by 230 kg ha^{-1} at one location (Reese and Buss, 1992). Double-crop soybean yield in Alabama increased 0.018 Mg grain kg N^{-1} with up to 75 kg N ha^{-1} NH_4NO_3 applied at planting (Taylor et al., 2005).

In Arkansas, 224 kg N ha^{-1} at V6 along with 112 kg N ha^{-1} at R2 as NH_4NO_3 produced 18% more grain under non-irrigated conditions, but no response was observed under irrigated conditions (Purcell and King, 1996). Irrigated studies of full-season and double-crop soybean in Virginia (Freeborn et al., 2001), Colorado (Halvorson and Reule, 2006), California (Beard and Hoover, 1971), New South Wales (Herridge and Brockwell, 1988) and Thailand (Jefing et al., 1992) also demonstrated no yield effect from applied N. Alternatively in Kansas, R3 N fertilization rates of 22 and 45 kg N ha^{-1} increased soybean yield at six irrigated, high-yielding locations by an average of 11.8% (Wesley et al., 1998). Under irrigation in Austria, 40 kg N ha^{-1} applied at R4 increased soybean yield by 38% compared to the untreated control (Afza et al., 1987). Irrigated studies of full-season soybean in Georgia (Gascho, 1993), Florida (Purcell et al., 2004), and Mississippi (Ray et al., 2006) also demonstrated increased soybean yield from N fertilization.

Timing of N application is also important, but trends are not always evident. Wilson et al. (2014) reported that an application of 560 kg N ha^{-1} split at planting (40%) and V5 (60%) increased yield for maturity group 3 soybean varieties, but not maturity group 2 soybean varieties. In Iowa, neither 45 kg N ha^{-1} nor 90 kg N ha^{-1} applied at R2 increased soybean yield (Barker and Sawyer, 2005). In Alabama, 56 kg N ha^{-1} applied at R1 did not affect yield. However, late-season R5 application at the same rate increased grain yield by as much as 733 kg ha^{-1}, but also decreased yield in some site-years (Wood et al., 1993). Although applying N after the R3 (first pod) growth stage has been shown to increase agronomic efficiency (unit of yield per unit of N applied) and recovery efficiency (increase in N uptake per unit of N applied) (Gan et al., 2002), it is still unclear if it consistently increases grain yield over and above applications before R3 growth stage (Salvagiotti et al., 2008).

1.4.3.2 Nitrogen Fixation and Accumulation

It is not surprising that N fertilization to soybean decreases BNF (Allos and Bartholomew, 1955; Ham et al., 1975; Harper, 1974; Kinugasa et al., 2012). This fact was stated as far back as 1916, “It has been known for a long time that the presence of certain salts in the soil has a tendency to retard the normal development of root nodules. This is especially true of the soluble salts of nitrogen, such as nitrates” (Fred and Graul, 1916). Nitrate in soil decreases nitrogenase and nitrate reductase activities, decreasing the amount of BNF in rhizobia. Nitrogenase is an important enzyme involved in N fixation (Luciñski et al., 2002; Sprent et al., 1988). In Austria, soybean fixed 16% of its N from the atmosphere when 20 kg N ha^{-1} was supplied, and it fixed only 5% when 100 kg N ha^{-1} was supplied (Hardarson et al., 1984). Plant uptake of N usually increased with fertilization even though BNF decreased. In Iowa, nodulating soybean accumulated 273 kg N ha^{-1} when 672 kg N ha^{-1} was applied, compared to only 244 kg N ha^{-1} for untreated plots (Hanway and Weber, 1971). This increase in uptake has also been supported by greenhouse studies (Allos and Bartholomew, 1955; Kinugasa et al., 2012; Thornton, 1947). Alternatively in Minnesota at 12 sites, N treatments of 84 kg N ha^{-1} (urea or polycoated urea, broadcast or injected, R2 or R4/R5) did not affect total biomass, biomass N concentrations, or ultimately, biomass N accumulation (Schmitt et al., 2001a).

1.4.3.3 Grain Nitrogen Removal and Composition

Jeppson et al. (1978) suggested that N fertilization to soybean did not affect NHI or N mobilization to grain. A greenhouse study in Japan reported that seed N concentration was not affected, but N fertilization after flowering increased N remobilization (Kinugasa et al., 2012). Ultimately, grain N removal was not affected by additional N in Iowa (Barker and Sawyer, 2005) or Colorado (Halvorson and Reule, 2006). In Minnesota, additional N on soybean increased seed protein concentration and decreased seed oil concentration, but increased total protein and oil production due to greater seed yields (Ham et al., 1975). A field and greenhouse study in Kentucky reported that seed protein content increased 4% when N was added at R1 or R4 (Brevedan et al., 1978). A comprehensive study in Indiana, Minnesota, Wisconsin, and Illinois reported application of 560 kg N ha^{-1} increased grain protein concentration for maturity group 2 soybean cultivars from the last 90 years, but maturity group 3 soybean grain protein was not affected. Grain oil concentration was not affected by additional N in either maturity group (Wilson et al., 2014). Although there has been evidence that additional N produces higher protein content, a Japanese study concluded that additional N did not affect seed protein percentage (Takahashi et al., 1992). In Virginia, 56 kg N ha^{-1} as UAN applied at R1 reduced grain protein content in full-season soybean compared to the untreated control, but the application did not affect double-crop soybean (Reese and Buss, 1992).

1.5 Swine Manure

1.5.1 Factors Affecting Manure Composition and Nitrogen Availability

1.5.1.1 Feed

In France, 67% of the N in the diet of the pig (*Sus scrofa domesticus*) was excreted (Dourmad et al., 1999), which could be lowered by reducing the protein content in the ration (Dourmad et al., 1992; Korniewicz et al., 2012; Portejoie et al., 2004). Pigs fed a low protein diet supplemented with amino acids (e.g., lysine, threonine, and tryptophan) excreted 30% less N (Walz et al., 1994), and the reduction of crude protein in swine ration (from 17% to 13%) increased N retention (i.e., decrease in N excretion) from 39% to 48% of N intake (Canh et al., 1998). Lowering the amount of dietary salt (NaCl) in the swine ration increased the proportion of ammonium N to Total Kjeldahl N in the manure (Sutton et al., 1976).

1.5.1.2 Category of pig

Manure produced by growing/finishing pigs (typically 30 to 130 kg) is 7.2% N (Hatfield et al., 1998). Growing/finishing pigs account for most (71%) of the N excreted on a normal farrow to finish operation, and sows and weaner pigs produce the remaining 19% and 10%, respectively (Dourmad et al., 1999). The daily amount of manure produced by pigs weighing 14 to 27 kg is 4.4 kg d^{-1}, and that number increases to 5.9 kg d^{-1} for pigs weighing 68 to 91 kg (Brumm et al., 1980). Therefore, a market pig will produce nearly 6 kg N via excretions throughout its rearing (Dourmad et al., 1999). A single barn that finished 4000 head would produce nearly 24,000 kg N per year, which would meet the N need for over 100 ha of corn at 225 kg N ha^{-1}.

1.5.1.3 Storage and Handling

Manure nutrient concentrations are largely variable, therefore it is common to see 50% variation from mean values (Lindley et al., 1988). Storage and handling of swine manure affects the N composition of the manure more than the pig diet (Hatfield et al., 1998) because 85% of the N in a pig diet is digested (McConnell et al., 1972). The loss of ammonium N can range from 10 to 90% depending on the storage and handling of the manure (Vanderholm, 1975). Swine manure is typically stored in a lagoon outside the building or in a pit under the building until it can be land applied. Lagoons are used on approximately 20 to 30% of swine farms, with the greatest use in the southern US, especially the Southeast. The manure in a lagoon separates into two parts: effluent and sludge. Anaerobic lagoons can have losses of 80 to 90% of the ammonium N through ammonia volatilization and denitrification, as compared to aerobic lagoons which have much lower losses (Hatfield et al., 1998).

The manure in pits under slatted floors in confinement buildings is considered a slurry. It is estimated that 50 to 60% of swine producers use this handling method of manure, and it is most common in the Corn Belt (Hatfield et al., 1998). In this type of setting in Canada, a barn housing 560 pigs lost roughly 1.34 kg N d^{-1} as ammonia (Burton and Beauchamp, 1986). Pertaining to lagoons or slurry pits, swine manure is not expected to lose much (if any) N as nitrous oxide (N_2O) due to lack of nitrate, degradable carbon, and oxygen (Monteny et al., 2001).

Alternative storage and handling methods include anaerobic digestion, flocculation, filtration, and decantation. These methods did not alter N_2O loss when compared to untreated manure (Chantigny et al., 2010), but an earlier study found a 50% reduction in N_2O loss with the use of anaerobic digestion (Chantigny et al., 2007). Anaerobic digestion reduced N_2O loss in other studies (Amon et al., 2006; Petersen, 1999; Vallejo et al., 2006), but it did not affect ammonia volatilization (Pain et al., 1990; Rubæk et al., 1996; Wulf et al., 2002).

1.5.1.4 Application Methods and Nitrogen Activity

Manure application methods also influence N availability for crops and the potential for N losses to the environment. Irrigated swine effluent lost 13% of the ammonium N due to volatilization during the irrigation process, and an additional 69% was volatilized within the first 24 hours following application in Georgia (Sharpe and Harper, 1997). Liquid and slurry manure is commonly surface applied (broadcast or banded) or injected. Surface applications typically volatilize more ammonia than injection methods. Surface-banded application decreased ammonia volatilization and increased crop N uptake when compared to surface-broadcast applications in British Colombia and Vermont (Bittman et al., 1999; Pfluke et al., 2011). In Indiana, the surface-broadcast application of liquid swine manure (90 to 180 Mg ha^{-1}) lost 11 to 16 % of its ammonium N over 3.5 days; whereas, only 2.5% was lost with injection (Hoff et al., 1981). In 8 days, 82.5% of the ammonium N was lost in a greenhouse study that simulated application of 135 Mg ha^{-1} of liquid swine manure (Hoff et al., 1981). In Sweden, 19.5% of ammonia was volatilized when pig slurry was surface-band applied as compared to only 1.2% when injected (Weslien et al., 1998), and injected manure increased corn leaf N concentration and corn yield more than other application methods and rates in Indiana (Sutton et al., 1982). In Denmark, crops recovered 38 to 43% of the N from injected pig slurry in the first 2.5 years following application; whereas, only 22 to 34% was recovered in the surface-banded treatment (Sørensen and Amato, 2002). Ammonia volatilization was likely the key difference in application effects on N utilization in both previously discussed studies, and other studies have similar findings (Dosch and Gutser, 1995; Hansen et al., 2003; Klausner and Guest, 1981).

On the other hand, a study from the United Kingdom comparing injected versus broadcast cattle slurry suggested that although ammonia volatilization was lower when the manure was injected, loss from denitrification was significantly greater (Thompson et al., 1987). In Germany, injected cattle slurry volatilized less ammonia than other treatments, but lost as much or more N_2O through denitrification (Wulf et al., 2002). In New Zealand, 30% of the N was denitrified when 200 to 400 kg ha^{-1} of pig slurry was injected to pasture (Carey et al., 1997). Other studies in Wisconsin and the Netherlands also found significant losses due to denitrification when cattle slurry was injected (Comfort et al., 1988; De Klein et al., 1996). Denitrification was greater in soil amended with liquid dairy manure than soil amended with NH_4NO_3 (29.5 vs. 3.2 kg N ha^{-1} over 49 days) (Loro et al., 1997). In Germany at 100 days after cattle slurry injection, 7.3 kg N

ha^{-1} was lost through denitrification as compared to only 4.5 kg N ha^{-1} with surface application (Dosch and Gutser, 1995).

Nitrate leaching losses can also be significant when manure is applied to agricultural soils. In Canada, 102 to 241 kg N ha^{-1} leached when dairy cattle slurry was surface applied at 600 kg N ha^{-1} (Paul and Zebarth, 1997). Nitrate leaching accounted for most of the loss because only 17% of NO_3-N was denitrified. Swine slurry application of 600 kg N ha^{-1} leached similarly (116 kg N ha^{-1}) in New Zealand (Cameron et al., 1995). However, nitrate leaching did not differ among surface-band application, surface-band application followed by harrowing, and injection of pig slurry in Sweden (Weslien et al., 1998). In contrast, tile water NO_3^- concentrations were greater when swine manure was injected in corn side-dress compared to top-dress application and concentrations increased as application rate increased (Ball Coelho et al., 2006).

Horizontal sweep injection has also been used. In Minnesota, soil inorganic N was 7 to 8% higher when horizontal sweep injection was compared to vertical injection of liquid manure; which subsequently resulted in higher corn yields (Schmitt et al., 1995).

1.5.1.5 Incorporation of Manure

Incorporation of swine manure increased corn yield and did not affect soybean yield when compared to broadcast application (Hanna et al., 2000). In Sweden, 19.5% of ammonia was volatilized when pig slurry was surface-band applied, but only 3.5% volatilized when the manure was incorporated by harrowing immediately following application. The incorporation numerically increased denitrification (Weslien et al., 1998). In Denmark, 41 to 45% of manure N was recovered by crops in the first 2.5 years following pig slurry application and incorporation to a depth of 10 cm; whereas, only 22 to 34% was recovered after a surface-banded application (Sørensen and Amato, 2002).

In Canada, solid beef manure increased subsurface (60 cm) N when applied at 60 Mg ha^{-1}. Moldboard plowing increased subsurface N on manure and control plots when compared to double disking, field cultivating, and no incorporation, but the interaction between tillage and manure application did not exist (Little et al., 2005). Chisel plow incorporation of liquid dairy manure in Wisconsin increased N leaching when compared to an equally timed no-till application of manure (Gupta et al., 2004).

1.5.1.6 Timing of Application

When discussing timing of application in terms of time of day, volatilization can be reduced by applying during the coolest part of the day or before a rain (Sommer and Hutchings, 2001). Modeling in Europe showed a 50% reduction in ammonia volatilization from applying in the morning or afternoon as compared to a noon application (Sommer and Olesen, 2000).

More important is the time of year that the manure is applied because the proportion of applied N lost to NO_3^- leaching can range from 0 to over 50%, with the highest amounts generally occurring from applications in the fall of the year (Smith et al., 2002). In the UK, 200 kg N ha^{-1} as swine slurry applied in September or October increased NO_3^- leaching, while December and January applications of the same rates did not differ from untreated plots (Beckwith et al., 1998). In New York, early fall applications of dairy cattle slurry to corn or grassland increased NO_3^- leaching compared to late fall or spring applications (Van Es et al., 2006).

In Canada, dry matter yield and crop N uptake of silage corn did not differ between the untreated control and 600 kg N ha^{-1} as liquid dairy manure applied in the fall. They attributed the overwinter loss of N to NO_3^- leaching and denitrification (Zebarth et al., 1996). At three responsive sites in England, 200 kg N ha^{-1} as spring-applied swine slurry increased grain N recovery in winter wheat (21%) when compared to fall-applied 300 kg N ha^{-1} (9%) (Jackson and Smith, 1997). Across three site-years in Minnesota, swine slurry applied in April increased corn yield by 690 kg ha^{-1} when compared to September and October applications, and soil NO_3^- concentrations did not differ with timing (Randall et al., 1999).

1.5.2 Effects in Soil

1.5.2.1 Nitrification

About 50% of the N in liquid swine manure is in the NH_4^+ form (Burns et al., 1987; Sutton et al., 1978). The NH_4^+ can either be taken up by a crop or be nitrified, which is the conversion of NH_4^+ to NO_3^-. Nitrification is favored by warm, aerobic conditions. Increased input of total N from manure application generally increases NO_3^- in soil (Gilmour et al., 1977).

1.5.2.2 Immobilization and Mineralization

Immobilization is the conversion of inorganic N to organic N. Immobilization can 'tie up' as much as 76% of NH_4^+ in soil following the application of anaerobically treated pig slurry (Bernal and Kirchmann, 1992). In Denmark, most immobilized N remained in the soil after 2 to 3 years following slurry application and contributed to long-term accumulation of soil organic N (Sørensen and Amato, 2002).

Generally, 20 to 80% of the N in manure is in the organic form depending on storage methods and feed rations (Beegle et al., 2008). This organic N and any N that was immobilized following manure application can be mineralized, which is the conversion of organic N to inorganic N (usually NH_4^+). Many factors affect N mineralization in the soil including soil temperature, moisture, and oxygen content (Jenkinson and Wild, 1988). The microbes responsible for mineralization operate optimally at 30 to 40˚ C (Brady and Weil, 1999).

The net result of immobilization (-) and mineralization (+) determines the amount of plant available N in soil following manure application. Many factors influence the final amount of plant available N (Beegle et al., 2008), but one of high importance is the composition of the manure (Serna and Pomares, 1991). This includes C:N ratio. Generally, a manure with a C:N ratio below 25:1 has more N mineralized than immobilized, while higher ratios tended have less mineralization and more immobilization (Brady and Weil, 1999). Handling of manure can also affect net N availability. In a Swedish incubation study, fresh pig slurry and anaerobically digested pig slurry treatments yielded a positive N release over 70 d, while the anaerobically fermented pig slurry did not (Kirchmann and Lundvall, 1993).

Mineralization rates in the soil can be affected by the addition of manure. Typically, immobilization occurs first with high rates of mineralization to follow. Then, mineralization rates plateau to rates comparable to untreated soil (Burger and Venterea, 2008; Kirchmann and Lundvall, 1993). Alternatively, mineralization rate never differed among untreated soil and soil treated with pig slurry in the UK (Flowers and Arnold, 1983).

1.5.2.3 Microbial Biomass and Activity

Microbial activities influence soil properties such as structure, nutrient availability, and organic matter turnover (Gregorich et al., 1996). Using microbial biomass carbon (C) content in soil and microbial biomass C/total organic C in soil ratios, a Spanish study (Plaza et al., 2004) concluded that the microbial biomass in the soil increased as 30, 60, 90, 120, and 150 m^3 ha^{-1} yr^{-1} of pig slurry was applied over 4 years. Those treatments all yielded higher microbial biomass C (311 to 442 mg kg^{-1}) when compared to the control (255 mg kg^{-1}) and mineral fertilizer treatment (247 mg kg^{-1}). Using measurements taken eight months after the final manure application, basal respiration as an indicator of microbial activity indicated no treatment effects. This non-effect was most likely due to the measurement timing since Rochette and Angers (2000) observed half of the total CO_2 emissions were released in the first week following band application of pig slurry (60 or 120 Mg ha^{-1}). Greater soil microbial respiration due to pig slurry application (as compared to mineral fertilizer treatment) was due to greater microbial mass rather than microbial activity (Rochette and Angers, 2000). Also in Canada, microbial biomass C and N were greater in the top 15 cm of soil when 90 m^3 ha^{-1} of liquid hog manure was side-dressed to corn (248 and 119 μg g dry $soil^{-1}$, respectively) when compared to the control (129 and 83 μg g dry $soil^{-1}$, respectively) and mineral fertilizer treatments (130 and 77 μg g dry $soil^{-1}$, respectively) (Lalande et al., 2000).

1.5.2.4 Organic Matter, Nutrients, and Physical Properties

Manure applications to cropland undoubtedly add nutrients and organic matter to soil, which can accumulate. In Canada, soil organic matter content increased from 18 g kg^{-1} to 36 g kg^{-1} in the top 30 cm after 11 years of annual 180 Mg ha^{-1} cattle manure applications (Sommerfeldt et al., 1988). In Spain, application of 51 m^3 liquid swine manure ha^{-1} yr^{-1} for 6 years increased soil organic matter by 5 g kg^{-1} and 3.6 g kg^{-1} when compared to lower treatments (0 and 29 m^3 ha^{-1} yr^{-1}, respectively) in the top 30 cm (Berenguer et al., 2008).

Despite method of application (broadcast or injection), the addition of 90, 135, and 180 t ha^{-1} of liquid swine manure increased soil accumulation of NO_3-N, NH_4-N, and especially P and K. The depth of accumulation, however, depended on application method (Sutton et al., 1982). A similar study using slightly lower rates of liquid swine manure (45, 90, and 135 t ha^{-1}) also increased nutrient accumulation (Sutton et al., 1978). Heavy metal toxicity can occur from excessive liquid swine manure application (L'Herroux et al., 1997), but although copper and zinc levels in soil rose after 6 consecutive years of 51 m^3 liquid swine manure ha^{-1} $year^{-1}$, the levels were not expected to reach toxicity for centuries (Berenguer et al., 2008).

In Canada, the bulk density of the top 15 cm of soil decreased by 0.002 g cm^{-3} for every 1 Mg ha^{-1} increment in cattle manure applied over 11 years regardless of tillage or irrigation effects (Sommerfeldt and Chang, 1985). A review of 21 different soil types and 7 types of waste/manure also observed the inverse relationship of bulk density and manure application rate (Khaleel et al., 1981). Along with improved pore size distribution and increased aggregation, this decrease in bulk density increased water holding capacity (Kladivko and Nelson, 1979).

1.5.3 Effects on Soybean

1.5.3.1 Yield

Soybean yield (2670 to 3270 kg ha^{-1}) increased linearly (1.4 kg kg^{-1} of applied available N) in three out of seven Minnesota locations when 145 to 413 kg N ha^{-1} was applied as liquid swine manure (Schmidt et al., 2001). In Brazil, application of 60 m^3 ha^{-1} liquid swine manure increased soybean yield by 25% to 2902 kg ha^{-1} compared to the untreated control (Sartor et al., 2012). In Ohio, manure and commercial fertilizer rates of 67 to 202 kg N ha^{-1} all increased soybean yield when compared to the untreated control with comparable tillage practices (i.e. injectors ran over untreated to compare with manure injection) (Mullen et al., 2008). Fall injection of liquid swine manure (~ 219 kg N ha^{-1} yr^{-1}) preceding soybean in a corn-soybean rotation study in Iowa increased soybean yield 130 kg ha^{-1} on average (Bakhsh et al., 2009). In another corn-soybean rotation study in Iowa, fresh and composted solid swine manure was applied (fall or spring) prior to corn and the residual effects of the manure increased soybean yield 6 to 15% (McAndrews et al., 2006). In Canada however, liquid swine manure (40, 80, and 160 kg N ha^{-1}) applied to barley had marginal to no residual effects on soybean yield the following season (Carter and Campbell, 2006). Also, in the Great Plains, manure had little to negative effects on soybean yield when soybean was grown consecutively or in rotation with grain sorghum (Roder et al., 1989). At eight site-years in Iowa yielding 2850 to 4390 kg ha^{-1}, liquid swine manure increased soybean yield at five locations by as much as 500 kg ha^{-1}. At three of those locations, both the low (93 to 165 kg N ha^{-1} as manure) and high (204 to 304 kg N ha^{-1} as manure) rates of manure increased soybean yield over the untreated control and did not differ from each other. Liquid swine manure application did not affect soybean yield at the remaining three locations (Woli et al., 2013).

1.5.3.2 Biomass Accumulation and Nitrogen Composition

Soybean treated with swine manure produced 26% more biomass 60 days after planting and 9% more biomass at R6 (full seed) than untreated soybean in Minnesota (Schmitt et al., 2001b). In a contrasting Minnesota study with higher N rates applied, liquid swine manure did not affect soybean R6 biomass when compared to the untreated control, with no early season data reported (Schmidt et al., 2000). Residual manure soybean was 6 to 12% taller throughout the season and stem diameters were 7 to 16%

thicker later in the season when compared to urea treatments and the untreated control in Iowa (McAndrews et al., 2006). In Ohio, injecting swine manure at 67, 134, and 202 kg N ha^{-1} resulted in more biomass at V4 than the untreated control and a linear increase in biomass was observed with N rate. By R1, soybean biomass was only increased over the untreated control when manure or commercial fertilizer was surface applied and incorporated; manure injection did not affect R1 biomass (Mullen et al., 2008).

Early season (V4) soybean N accumulation was increased over the untreated control in Ohio by injecting swine manure; and by R1, N accumulation was increased over the untreated control by injecting or surface applying manure or surface applying commercial fertilizer (Mullen et al., 2008). Total N accumulation of soybean at R6 increased by 10% over the untreated control when averaged across two varying liquid swine manure rates at seven locations in Minnesota. This increase was a result of a statistical increase in both biomass and N concentration of biomass. Biomass N concentrations were 4 to 19% higher throughout the growing season for soybean treated with a high rate of swine manure compared to the untreated control, with greater differences measured earlier in the season (Schmitt et al., 2001b). Liquid swine manure injections (100, 200, 300, 400, or 500 kg N ha^{-1}) prior to planting eight soybean isolines increased N accumulation at R6 by 11 kg N ha^{-1} when compared to mineral fertilizer rates in Minnesota. This study reported only numerical increases in biomass and biomass N concentration and no manure rate effect on N accumulation (Schmidt et al., 2000).

1.5.3.3 Residual Soil Nitrogen

Residual soil N from swine manure application can be an environmental issue if the application rate is greater than the amount of N accumulated in soybean biomass and grain. In Minnesota, swine manure applications of greater than 260 kg N ha^{-1} resulted in 80 to 158 kg N ha^{-1} remaining as NO_3^- in the top 120 cm after soybean harvest. The results did not differ among nodulating vs. non-nodulating soybean or among manure N vs. mineral fertilizer N, and data for untreated soybean was not shown (Schmidt et al., 2000). In Ohio, injected manure and surface applied commercial fertilizer at 67 to 202 kg N ha^{-1} supplied more N throughout the growing season than the untreated control in the top 30 cm of soil; though, after harvest, those differences disappeared. Manure and commercial fertilizer N levels at 30 to 60 cm also did not differ from the untreated control after harvest (Mullen et al., 2008).

1.6 Objective of Research

Very little, if any, research has been done to test the effects of swine manure on double-crop soybean following wheat in the Midwest. We used three rates of liquid swine manure from confinement finishing barns, three rates of UAN fertilizer, and an untreated control to compare effects on double-crop soybean in central and southern Indiana. The objective of this research was to determine the capacity of double-crop soybean to manage N from swine manure as compared to N from commercial fertilizer, which included the effects on (1) biomass production and N accumulation,

(2) grain yield and grain N removal, and (3) soil N balance during the season and after harvest.

CHAPTER 2. SWINE MANURE APPLICATIONS TO DOUBLE-CROP SOYBEAN: EFFECTS ON PLANT GROWTH, YIELD, AND SOIL

2.1 Abstract

Animal production, especially swine (*Sus scrofa domesticus*) and poultry has increased in the United States prompting the need to manage the larger volume of manure beyond land applications to supply nitrogen (N) for corn (*Zea mays L.*) production. Applying swine manure to soybean (*Glycine max*) has been shown to increase grain yield due to N supply. The objective of the research was to determine if swine manure applications for double-crop soybean following wheat can limit manure N loading to the soil, increase soybean biomass and grain production, and increase N removal rates. Four field-scale trials were initiated in 2012 near Russiaville, IN and Farmland, IN and in 2013 near Farmersburg, IN and Fort Branch, IN. Three rates of swine manure were applied ranging from 116 to 599 kg N ha^{-1} depending on location. Fertilizer UAN was also applied at 168, 336, and 504 kg N ha^{-1}, and an untreated control (UTC) was included. Biomass and nutrient accumulations were determined with plant samples at full bloom (R2) and full seed (R6), and grain subsamples at harvest. Soil N was determined for the 0 to 30 and 30 to 60 cm depths at R2 and post-harvest. Swine manure application increased soybean grain yield in conjunction with increased application rates of manure in 2012 at Russiaville. This increase of yield was preceded by increased biomass accumulation at R2, but N application generally did not affect biomass accumulation at R6. All treatments

resulted in more N in the top 60 cm of soil after harvest compared to the UTC. In 2013, effects of swine manure application to soybean were negligible to negative. At Farmersburg, grain yield was negatively affected by manure application, and significant amounts of soil N were present after harvest in the manure-amended plots. At Fort Branch, biomass, grain yield, grain N removal, and post-harvest soil N were not affected by swine manure application suggesting less benefit from swine manure in a high yield environment with adequate moisture. Overall, manure application to double-crop soybean can be a sound manure management option if it can be executed with minimal soil disturbance, and it is especially beneficial for those producers that need to free up manure storage space.

2.2 Introduction

Soybean (*Glycine max*) production in the US is concentrated in the Midwestern states of Illinois, Iowa, Minnesota, Missouri, and Indiana which harvested 3.8, 3.7, 2.7, 2.2, and 2.1 million ha in 2013, respectively (USDA-NASS, 2014). Swine (*Sus scrofa domesticus*) production in the US has doubled since the 1970s (Quick Facts NPB, 2012) and is concentrated in the Midwestern states and North Carolina. Iowa, North Carolina, Minnesota, and Illinois accounted for over 60% of the US swine production, and Indiana ranked fifth in the US (Plain, 2008). The top soybean and swine producing states intersect, so manure management using soybean systems is a practical option to explore.

Many growers in the Midwest and the southern US raise wheat (*Triticum spp.*) and soybean in a double-crop system to increase profitability. Although double-cropping may be more profitable, it is widely known that soybean yields decrease as planting date is delayed. These lower yields were likely due to moisture stress later in the season, heat stress, or a shortened growing season (i.e., limited photoperiod) (Hu and Wiatrak, 2012). Nevertheless, this double-crop production system could provide an opportunity for swine manure application to land at a convenient time between spring and fall.

Soybean requires a large amount of N to support above ground biomass and to produce seed that is high in protein (Salvagiotti et al., 2008). Soybean N requirements are often overlooked because soybean receives most of its N from the soil and biological N fixation (BNF). Biological N fixation can contribute 84% of N taken up by inoculated soybean, but can contribute as little as 44% when 200 kg N ha^{-1} was applied to non-inoculated soybean (Hungria et al., 2006). Soybean was grown in outdoor hydroponic gravel culture with varying rates of nitrate supplied, and the highest yields (15 g seed $plant^{-1}$) were obtained on those plants that utilized both BNF and available nitrate. Harper (1974) noted that 200 kg N ha^{-1} maximized soybean yield, which had lower yield potential than today.

Yield of soybean is not consistently increased by supplemental N applications. In a review of 108 studies between 1966 and 2006, a positive yield response was present in half the studies and yield increase averaged 520 kg ha^{-1} (Salvagiotti et al., 2008). This also held true for double-crop soybean. Averaged over three environments in Virginia, UAN applied at planting or R1 (first bloom) at a rate of 56 kg N ha^{-1} did not affect double-crop soybean yield and even decreased yield at one location with the application at R1 (Reese and Buss, 1992). Whereas, double-crop soybean yield in Alabama increased 18 kg ha^{-1} for every kg of N up to 75 kg N ha^{-1} when NH_4NO_3 was applied at planting (Taylor et al., 2005).

Supplemental N on soybean consistently decreases BNF (Allos and Bartholomew, 1955; Ham et al., 1975; Harper, 1974; Kinugasa et al., 2012), but has inconsistent effects on biomass, biomass N accumulation, and grain composition. In Iowa, nodulating soybean accumulated 273 kg N ha^{-1} when 672 kg N ha^{-1} was applied, compared to only 244 kg N ha^{-1} for untreated plots (Hanway and Weber, 1971). This increase in uptake has also been supported by greenhouse studies (Allos and Bartholomew, 1955; Kinugasa et al., 2012; Thornton, 1947). Alternatively in Minnesota at 12 sites, N treatments of 84 kg N ha^{-1} (urea or polymer-coated urea, broadcast or injected, R2 – full bloom or R4/R5 – first pod to full pod) did not affect total biomass, biomass N concentrations, or ultimately, biomass N accumulation of soybean (Schmitt et al., 2001a). A comprehensive study in Indiana, Minnesota, Wisconsin, and Illinois reported that the application of 560 kg N ha^{-1} did not increase grain yield but did increase grain protein concentration for maturity group 2 soybean cultivars from the last 90 years. In contrast, the maturity group 3 soybean cultivars did increase in yield, but grain protein concentration was not affected. Grain oil concentration was not affected by additional N in either maturity group (Wilson et al., 2014).

Swine manure composition is affected by feed ration (Dourmad et al., 1992), category of pig (Dourmad et al., 1999), and storage and handling of the manure (Hatfield et al., 1998). Manure nutrient availability to plants is affected by manure composition (Sutton et al., 1976), application method (Hoff et al., 1981), incorporation of manure (Hanna et al., 2000), and timing of application (Smith et al., 2002).

In conjunction with supplemental N on soybean, swine manure also has inconsistent effects on soybean yield, biomass, and N accumulation. Soybean yield (2670 to 3270 kg ha^{-1}) increased linearly (1.4 kg ha^{-1} for every kg available N applied per ha) in three out of seven Minnesota locations when 145 to 413 kg N ha^{-1} was applied as liquid swine manure (Schmidt et al., 2001). In Ohio, manure and commercial fertilizer rates of 67 to 202 kg N ha^{-1} all increased soybean yield when compared to the untreated control with comparable tillage practices (i.e., injectors ran over the untreated control to compare with manure injection) (Mullen et al., 2008). Alternatively in the Great Plains, manure had little to negative effects on soybean yield when soybean was grown consecutively or in rotation with grain sorghum (Roder et al., 1989). Soybean treated with swine manure produced 26% more biomass 60 d after planting and 9% more biomass at R6 (full seed) than untreated soybean in Minnesota (Schmitt et al., 2001b). In a contrasting Minnesota study with higher N rates, liquid swine manure injections did not affect soybean biomass at R6 when compared to the untreated control, with no early season data reported. Manure injection (100, 200, 300, 400, or 500 kg N ha^{-1}) prior to planting eight nodulating soybean isolines increased N accumulation at R6 by 11 kg N ha^{-1} when compared to mineral fertilizer rates. This study reported only numerical increases in biomass and biomass N concentration and no manure rate effect on N accumulation (Schmidt et al., 2000).

Residual soil N from swine manure application can be an environmental issue if the application rate is greater than the amount of N accumulated in soybean biomass and grain. In Minnesota, swine manure applications greater than 260 kg N ha^{-1} resulted in 80 to 158 kg N ha^{-1} remaining as nitrate in the top 120 cm after soybean harvest. The results did not differ among nodulating vs. non-nodulating soybean or among manure N vs. mineral fertilizer N, and data for untreated soybean was not shown (Schmidt et al., 2000).

In Ohio, injected manure and surface applied commercial fertilizer at 67 to 202 kg N ha^{-1} contained more N throughout the growing season than the untreated control in the top 30 cm of soil; though, after harvest, those differences disappeared. Soil N measured in the manure and commercial fertilizer treated plots at a depth from 30 to 60 cm also did not differ from the untreated control after harvest (Mullen et al., 2008).

The objective of this research was to determine the capacity of double-crop soybean to manage N from swine manure as compared to N from commercial fertilizer, which included the effects on (1) biomass production and N accumulation, (2) grain yield and grain N removal, and (3) soil N balance during the season and after harvest.

2.3 Materials and Methods

2.3.1 Site Characterization

The experiment was conducted at four Indiana locations in 2012 and 2013 (Table 2-1). Early wheat harvest in 2012 enabled the trials to be located in north-central Indiana (Russiaville and Farmland). Success of double-crop soybean after wheat is dependent upon the growing season for north-central Indiana. Double-crop soybean production is common in southern Indiana, which was the region of the 2013 trials (Farmersburg and Fort Branch). Though, wheat harvest was later than normal in Indiana in 2013. Wheat yields for the four locations ranged from 4304 to 6456 kg ha^{-1} and wheat straw was removed at Russiaville and Fort Branch prior to planting soybean (Table 2-1). General soil fertility was not limiting with samples from 0 to 20 cm in the untreated control (UTC) plots (Table 2-2).

Manure was swine slurry from confined finishing barns (Table 2-3) and was sampled three to eight times throughout application day depending on location. Total Kjeldahl Nitrogen (TKN) in manure at Russiaville, Farmland, Farmersburg, and Fort Branch was 5.1, 2.7, 6.4, and 5.7 kg N 1000 L^{-1}, respectively. Phosphorus (P) concentrations were 1.3, 0.8, 1.4, and 2.9 kg P_2O_5 1000 L^{-1}, respectively by location. Potassium (K) concentrations were 3.2, 2.8, 4.4, and 3.1 kg K_2O 1000 L^{-1}, respectively by location. The resulting N:P:K ratios reported as TKN:P_2O_5:K_2O were 3.9:1:2.5, 3.4:1:3.5, 4.6:1:3.1, and 2.0:1:1.1, respectively for Russiaville, Farmland, Farmersburg, and Fort Branch.

2.3.2 Experimental Design

Seven treatments were arranged in a randomized complete block design with four replications at Russiaville and three replications at all other sites. Treatments were three rates of urea-ammonium nitrate (UAN) (168, 336, and 504 kg N ha^{-1}), three rates of manure (dependent upon location), and one untreated control (UTC) with no applied N. The resulting total N (TKN) rates applied are listed in Table 2-4. Manure and UAN were injected at a 5 to 30 cm depth (Table 2-4) following wheat harvest and prior to planting double-crop soybean. Nitrogen rates using UAN remained constant across site-years to give comparable data. These rates were meant to supply distinct rates of N including a non-limiting supply on the top end. Manure N targets were the same as UAN and based on total N supply (not plant available N), but the variable nature of manure and applicator capacities reduced and/or increased the actual manure N applied. A flow meter was used at Farmland to ensure accurate manure application rates. Flow meters were not available at the other three locations, but commercial applicators were calibrated prior to application and treatment rates were achieved by changing application speed. The trials were field-scale with plot size of 0.22 ha at Russiaville, 0.12 ha at Farmland, 0.23 ha at Farmersburg, and 0.09 ha at Fort Branch.

Wheat was the previous crop, and its grain yield and straw removal are reported in Table 2-1. No additional tillage was incorporated at any locations except Farmersburg where manure plots were field cultivated following manure application and prior to planting. This was necessary due to deeper injection resulting in a very rough soil surface. To avoid seedling burn of an entire row, soybean was planted across manure injection bands at a 90˚ angle at all locations, except Farmland where soybean was planted at 45˚. Soybean row spacing was 19 cm at Farmland and Fort Branch and 38 cm at Russiaville and Farmersburg. Soybean maturities were typical for the areas (Table 2-1). Weed control was executed per cooperators practices and was adequate at each site-year.

2.3.3 Data Collection and Analysis

2.3.3.1 Soybean Biomass and Nutrient Uptake

Whole plant samples were taken at the R2 (full bloom) and R6 (full seed) growth stages (Table 2-5). Three subsamples were composited for each plot. Sampling areas were 0.84 to 1.16 m^2 at R2 depending on row spacing and 0.58 to 1.16 m^2 at R6 depending on row spacing, and data were then adjusted to the standard area of kg ha^{-1}. All plants were counted for each sampling area to determine plant population. Main-stem nodes were counted at each growth stage. Plant samples were dried at 60˚C for a minimum of 4 days, then weighed, chopped, finely ground, and analyzed by A&L Great Lakes Labs (Fort Wayne, IN) for macro- and micro-nutrients. Biomass was determined on a per plant basis by using total sample weight divided by number of plants in the sample and was also determined on a kg ha^{-1} basis using total sample weight divided by sampling area then scaled to ha. Nitrogen accumulation was determined by multiplying N concentration of biomass by total biomass accumulation on a kg ha^{-1} basis.

Plots were harvested using a farm-scale combine at each location. Only the center of the plots were harvested and plot widths were 1.5 to 2 times the width of the combine header. Yield data were obtained from a calibrated yield monitor at each location and grain yield was reported on a 13% moisture basis. Grain samples were collected for each plot while the plots were being harvested to get a representative sample of the whole plot. Seed size was determined by weighing 200 seeds, and seed weight was reported in g 100 $seeds^{-1}$ and adjusted to 13% moisture. Protein and oil concentrations were determined using an Infratec® 1229 Whole Grain Analyzer via NIR analysis. A portion of each grain sample was then dried at 38˚C for a minimum of one week and ground for nutrient analysis. Grain N removal was determined using grain N concentration multiplied by yield in kg ha^{-1} adjusted to dry basis. An N ratio was also derived by dividing grain N removal by total N accumulation at R6 to provide an indication of N remobilization from maximum uptake (~R6) to grain harvest.

2.3.3.2 Soil Fertility and Nitrogen

Dates of data collection are listed in Table 2-5. Due to time constraints and dry soil conditions, site characterization soil samples were not taken on each plot prior to manure and UAN applications. Therefore, 0 to 20 cm soil samples (Table 2-2) were taken on the untreated control plots at the R2 growth stage and results were averaged for soil characterization of each site. Deep soil samples (0 to 30 and 30 to 60 cm) were taken with hand probes or a probe tractor at R2 (full bloom) and after harvest (within ~1 week) where field conditions were fit. Extremely dry field conditions during early sampling (R2) prevented sampling at Farmland in 2012 and limited sampling at Farmersburg in 2013. Thus, only soil from the UTC, the high rate of manure, and the high rate of UAN were sampled at R2 at Farmersburg in 2013. Manure and UAN injection bands were taken into account during soil sampling. Injection bands were 102 cm apart at Russiaville. At R2, a probe tractor was used to collect three sets of subsamples (front, middle, and back of each plot). Five cores were taken within each set of subsamples to total 15 cores per plot. Each subsample set consisted of one core taken directly in the injection band, one core taken on each side 25 cm from the injection band, and one core on each side 51 cm from the injection band. At Farmersburg and Fort Branch at R2, two cores were taken for each of seven subsample sets throughout the plots. Injection bands were 76 cm on center, so representative sampling was achieved by collecting soil cores that were perpendicular to the injection bands and 38 cm apart. This sampling scheme was also used at all four locations post-harvest. Soil samples were separated into 0 to 30 cm and 30 to 60 cm depths for separate analysis. Soil samples were air-dried in the greenhouse for about a week depending on weather conditions and ground to pass through a 2 mm screen. General fertility samples were taken on each plot post-harvest at 0 to 20 cm.

All general fertility of soil, plant, grain, and manure samples were analyzed by A&L Great Lakes Lab in Fort Wayne, IN (all procedures listed in Tables 2-2 and 2-3). All soil samples that were analyzed for N only were analyzed at Purdue University. Soil N samples were air-dried in the greenhouse for about a week depending on weather conditions, then ground and extracted for NO_3-N and NH_4-N with a 1:10 ratio of dry soil (5 g) to KCl (50 ml). The soil-KCl mixture was shaken for one hour at 65 rpm oscillation in 250 ml Erlenmeyer flask (McTaggart and Smith, 1993). The mixture was then filtered into 20 ml scintillation vials with Whatman #42 filter paper, then one drop of chloroform was added to each vial to preserve the sample. The soil-KCl extractant was analyzed for nitrate (reported as NO_3-N) and ammonium (reported as NH_4-N) on a Skalar San^{++} Automated Wet Chemistry Continuous Flow Analyzer from Skalar Analytical, The Netherlands.

Soil N content (kg N ha^{-1}) was estimated based on measured N concentrations (mg N kg^{-1}) and estimated bulk density. Bulk densities from Web Soil Survey were obtained for each depth (0 to 30 cm and 30 to 60 cm) using values for one third bar soil bulk density. Bulk density results were averaged across all soil types equally at each of the locations, and an average for 0 to 30 cm and a separate average for 30 to 60 cm was used in calculating soil N content at each location.

2.3.4 Statistical Analysis

All variables were considered for transformation before analysis. The only transformations that were performed were a Log_{10} on the soil N variables NO_3-N and total inorganic N. Data were subjected to an analysis of variance (ANOVA) in PROC GLM of SAS version 9.3 (SAS Inst., Cary, NC). Means separation was conducted using Fisher's Protected Least Significant Difference at $\alpha = 0.05$ ($FLSD_{0.05}$) when ANOVA marked significance at $p<0.05$ and at $\alpha = 0.10$ ($FLSD_{0.10}$) when ANOVA marked significance at $p<0.10$. Where transformations were used, analysis was conducted on transformed data and results are reported as back-transformed data. Due to varying rates of manure between site-years, locations were not combined and will be discussed separately.

2.4 Results and Discussion

2.4.1 Growing Environment

Growing conditions and 30-yr (1981-2010) averages for all site-years are listed in Table 2-6. Weather data for the Farmland location were obtained from a weather station on-site. Weather data for all other locations were obtained from the closest weather stations available. Russiaville and Fort Branch stations were located 6.5 km northeast and 12.3 km northwest of the trial locations, respectively. Farmersburg 2013 data and 30-yr monthly normal precipitation were obtained from a weather station 5 km southeast of the plots, however 30-yr monthly temperatures were obtained from a station 20.7 km southeast of the trial.

The 2012 growing season was in the middle of a drought with above average temperatures and below average rainfall in May, June, and especially July. Subsequently, wheat harvest occurred approximately two weeks ahead of normal in the central part of Indiana allowing for double-crop soybean to be grown. Double-crop soybean can always be grown in southern Indiana, but it is dependent upon the year whether it can be grown in central Indiana. The weather turned in August to slightly below average temperatures and above average rainfall, which helped soybean trials, especially at Russiaville. A fall freeze when soybean was at the R5 growth stage damaged the Farmland trial. A major freeze in October caused significant damage at Farmland when soybean was at the R5.5 to R6 stage and minor damage at Russiaville when soybean was at late R6 growth stage.

The combination of moderate to lower temperatures and abundant precipitation in June 2013 delayed wheat development and harvest by about two weeks. Subsequently, manure application and double-crop soybean planting were two to three weeks later than in 2012. Precipitation totals were well below 30-yr averages in August and September 2013 (Table 2-6). Farmersburg and Fort Branch received only 13.1 and 5.6 mm of rainfall in August, respectively. Abundant precipitation (85 mm) in September helped soybean at Fort Branch, but soybean at Farmersburg struggled with only 39 mm. Temperatures in 2013 deviated very little from 30-yr averages during the double-crop soybean, growing season at both locations.

2.4.2 Soil Fertility

2.4.2.1 Soil Fertility at Full Bloom

General soil fertility at R2 taken from the UTC plots was within recommended levels (Table 2-2). Critical levels for soybean in Indiana are 20 mg Mehlich-3 P kg^{-1}, 100 to 125 mg Mehlich-3 K kg^{-1}, and pH of 6.0 to 6.5. Organic matter content and pH across locations ranged from 2.2% to 3.5% and 5.9 to 6.4, respectively. Phosphorus was 40 to 110 mg Mehlich-3 P kg^{-1}, and potassium was 117 to 175 mg Mehlich-3 K kg^{-1} (Table 2-2). Manure supplied 15 to 133 kg P ha^{-1} and 97 to 342 kg K ha^{-1} across locations (Table 2-7).

2.4.2.2 Soil Nitrogen at Full Bloom

Soil N concentrations (mg kg^{-1}, Table A-1) were used to calculate soil N content (kg ha^{-1}, Table 2-8), which was related to the N rates applied and the N taken up by soybean. Total inorganic N levels in the UTC in the top 30 cm ranged from 27 to 40 kg N ha^{-1} and in the 30 to 60 cm depth theses values ranged from 16 to 19 kg N ha^{-1} across locations (Table 2-8). These values are low considering manure supplied 116 to 599 kg N ha^{-1} across locations. At R2, treatments affected soil NO_3-N and total inorganic N at all sampled locations and depths, and NH_4-N was affected in the top 30 cm at Russiaville (Table 2-9). Nitrate-N and NH_4-N trends followed total inorganic N trends with NO_3-N generally accounting for 50 to 90% of the total inorganic N in the soil from manure and UAN treatments and 25 to 50% for the UTC. At comparable N rates, UAN generally had more total inorganic N in the top 60 cm as compared to manure.

At Russiaville, all manure and UAN treatments resulted in more total inorganic N in soil than the UTC (40 kg N ha^{-1} in 0 to 30 cm and 19 kg N ha^{-1} in 30 to 60 cm). The high manure rate (431 kg N ha^{-1} applied) contained 129 and 29 kg N ha^{-1} for the upper and lower depths, respectively. In comparison, the high (504 kg N ha^{-1} applied) and medium (336 kg N ha^{-1} applied) UAN rates contained 285 and 158 kg N ha^{-1} in the top 30 cm and 36 and 32 kg N ha^{-1} in the 30 to 60 cm depth, respectively. In this case, total inorganic N accounted for 57 to 64% of applied N from UAN whereas only 36% of applied N from manure in the top 60 cm.

At Farmersburg, only the UTC and high rate plots were sampled. Both high manure (597 kg N ha^{-1} applied) and high UAN (504 kg N ha^{-1} applied) contained more total inorganic N than UTC in the top 30 cm, but only high UAN contained more total inorganic N than the UTC in the lower depth. This was likely due to increased NO_3-N movement down the profile in UAN due to differing compositions of N in manure (NH_4-N + organic N) and UAN (NH_4-N + NO_3-N). Of the 597 kg N ha^{-1} applied to the high manure plots, 242 kg N ha^{-1} and 20 kg N ha^{-1} were contained in the top 30 cm and 30 to 60 cm, respectively. This was 44% of the total applied N as manure in the top 60 cm as inorganic N. Fifty percent of the N applied at the high rate of UAN was present as inorganic N in the top 30 cm and 30 to 60 cm (228 and 23 kg N ha^{-1}, respectively). This is compared to 27 kg N ha^{-1} in the top 30 cm and 16 kg N ha^{-1} in the lower depth contained in the UTC.

At Fort Branch, only the high and medium rates of manure (399 and 599 kg N ha^{-1} applied, respectively) and UAN (336 and 504 kg N ha^{-1} applied, respectively) supplied more total inorganic N at R2 in the top 30 cm than the UTC. In the 30 to 60 cm depth, only the high and medium UAN rates supplied more total inorganic N than UTC. Of the 399 kg N ha^{-1} applied to the medium manure plots, 103 kg N ha^{-1} and 24 kg N ha^{-1} were present in the top 30 cm and 30 to 60 cm, respectively. This was 32% of the total N applied as manure in the top 60 cm as inorganic N. Fifty-three and 76% of N applied at the high and medium rates of UAN was present as inorganic N in the top 30 cm (212 and 221 kg N ha^{-1}, respectively) and 30 to 60 cm (56 and 36 kg N ha^{-1}, respectively). This is compared to 33 kg N ha^{-1} in the top 30 cm and 17 kg N ha^{-1} in the lower depth contained in the UTC.

In summary, more N was available to soybean at R2 in UAN treated plots as compared to manure plots, and both sources supplied more available N than the UTC. In other words, a larger portion of the applied N as UAN was in the inorganic form in the top 60 cm of soil as compared to manure applied N. Also, NO_3-N movement down the soil profile occurred in greater quantities in UAN plots by the R2 sampling compared to manure plots. In the top 30 cm of soil, similar manure N application rates at Russiaville (431 kg N ha^{-1} applied) and Fort Branch (399 kg N ha^{-1} applied) contained 129 and 103 kg N ha^{-1} as inorganic N, respectively. Those same treatments contained 29 and 24 kg N ha^{-1} as inorganic N in the lower 30 cm. The previous manure N rates fall between the medium (336 kg N ha^{-1} applied) to high (504 kg N ha^{-1} applied) UAN rates, which contained 158 to 285 kg N ha^{-1} as inorganic N solidifying the fact that UAN supplied more inorganic N in the top 30 cm at R2 than manure. The same was true for the 30 to 60 cm depth, where UAN contained 32 to 56 kg N ha^{-1} yet medium manure contained 24 kg N ha^{-1} at Fort Branch (Table 2-8).

2.4.2.3 Soil Fertility Post-Harvest

General soil fertility (0 to 20 cm) after harvest did not show consistent treatment effects (Table 2-9), but some trends were evident. Farmland data (Table A-3) will not be discussed due to extreme drought conditions and early fall freeze that compromised soybean grain yields and subsequent nutrient removals.

Treatments did affect P ($p<0.05$) at Fort Branch and K ($p<0.1$) at Russiaville and Farmersburg (Tables 2-7 and 2-9). At Fort Branch, post-harvest soil P was highest in soil amended with high rate of manure (51 mg P kg^{-1}) compared to all other treatments (30 to 39 mg P kg^{-1}, Table 2-7). The manure-amended soils at Farmersburg and Russiaville showed similar numerical increases in P compared to the UTC. Though, soil P concentrations of all treatments at all locations were all above critical level (20 mg Mehlich-3 P kg^{-1}) for soybean (Table 2-7).

Potassium trends were similar for all three locations with manure-amended soils generally containing more K than other treatments after harvest (Table 2-7). At Russiaville, soil amended with the high manure rate contained 184 mg K kg^{-1}, which was more than all other treatments (113 to 148 mg K kg^{-1}) except soil amended with medium rate of manure (164 mg K kg^{-1}). Similarly, medium and high rates of manure resulted in more soil K (168 and 184 mg K kg^{-1}, respectively) than the remaining treatments at Farmersburg. Potassium levels did not differ at Fort Branch, but soil amended with high rate of manure was numerically the highest (165 mg K kg^{-1}). Soil K concentrations of all treatments at all locations were all above critical levels (100 to 125 mg Mehlich-3 P kg^{-1} depending on CEC) for soybean (Table 2-7).

Manure-amended soils were usually higher in the remaining fertility concentrations if any differences or numerical trends existed. Soil pH showed only numerical differences across locations (Table 2-7), whereas treatments differed for sulfur (S) at Russiaville, zinc (Zn) at Fort Branch, and iron (Fe) at Farmersburg and Fort Branch (Table 2-10). At Russiaville, S ranged 11 to 15 mg S kg^{-1} for manure-amended soils, whereas UAN-amended soils and the UTC ranged 8.3 to 9.5 mg S kg^{-1}. Zinc at Fort Branch ranged 3.3 to 3.5 mg Zn kg^{-1} for UAN-amended soils and ranged 3.8 to 5.3 mg Zn kg^{-1} for manure-amended soils, while the UTC had 3.7 mg Zn kg^{-1} after harvest. Also at Fort Branch, Fe was greater in manure-amended soils (234 to 256 mg Fe kg^{-1}) compared to UAN-amended soils and the UTC which ranged 207 to 224 mg Fe kg^{-1}.

In summary, general soil fertility was not limiting for any treatments at any locations, and manure-amended soils had more P and K than other treatments at some locations after harvest. Manure-amended soils also contained more S, Zn, and Fe in some cases.

2.4.2.4 <u>Soil Nitrogen Post-Harvest</u>

Soil N concentrations (mg kg^{-1}, Table A-2) were used to calculate soil N content (kg ha^{-1}, Table 2-11), which will be related to the N rates applied and the N taken up by soybean. Total inorganic N and NO_3-N in the soil was consistently affected by treatment after the growing season at Russiaville and Farmersburg. Soil NO_3-N trends were very similar to total inorganic N (Tables 2-9 and 2-11), so only total inorganic N will be discussed in detail. Medium and high rates of UAN (336 and 504 kg N ha^{-1} applied) and the high rate of manure (431 kg N ha^{-1} applied) contained the most N in the upper 30 cm at Russiaville (56, 58, and 49 kg N ha^{-1}, respectively). The remaining treatments did not differ from each other, and the UTC contained 23 kg N ha^{-1} (Table 2-11). Similar results were reported in Minnesota where swine manure applications of greater than 260 kg N ha^{-1} resulted in 80 to 158 kg N ha^{-1} remaining as NO_3-N in the top 120 cm after soybean harvest. The results did not differ among manure N vs. mineral fertilizer N, and data for untreated soybean was not shown (Schmidt et al., 2000).

The maximum amount of manure that can be applied to soybean in Indiana is 168 kg “plant-available” N ha^{-1} (USDA-NRCS and IDEM, 2001). Plant available N is defined as NH_4-N, NO_3-N, and the percent of organic N that will mineralize in one growing season. Therefore, when manure was applied at rates close to the maximum amount allowed (e.g., 187 kg N ha^{-1} applied at Russiaville), no extra N was present in the upper 30 cm when compared to the UTC. At Russiaville at a depth of 30 to 60 cm, all treatments contained more N than the UTC with 117 kg N ha^{-1} remaining in the high UAN plots, 58 kg N ha^{-1} remaining in the high manure-amended soils (431 kg N ha^{-1} applied), and only 18 kg N ha^{-1} remaining in the UTC.

At Farmersburg, all treatments excluding the low UAN rate contained more N than the UTC in the top 30 cm. All three manure rates and the high UAN rate contained more N in the 30 to 60 cm depth than the UTC. The medium manure rate (412 kg N ha^{-1} applied) left 144 kg N ha^{-1} in the top 30 cm of soil and 58 kg N ha^{-1} at a depth of 30 to 60 cm, which was similar to the soils amended with the medium to high rates of UAN (336 to 504 kg N ha^{-1} applied) that contained 83 to 175 kg N ha^{-1} in the upper depth and 31 to

63 kg N ha^{-1} in the lower depth. The UTC contained only 26 and 18 kg N ha^{-1} in the upper and lower depths, respectively.

Soil N content did not differ among treatments at Fort Branch (average of 65 kg N ha^{-1} in top 60 cm). This is in agreement with an Ohio study that reported soil inorganic N in the top 60 cm did not differ among swine manure and commercial fertilizer applications of 67 to 202 kg N ha^{-1} to soybean compared to the UTC (Mullen et al., 2008). Soil NH_4-N was only affected at Russiaville in the top 30 cm, and content was low (2 to 3 kg NH_4-N ha^{-1}). Soil NH_4-N did not differ among treatments at Farmersburg or Fort Branch in the top 30 cm (~14 and 17 kg NH_4-N ha^{-1}, respectively) nor in the bottom 30 cm at any of the locations (averages from 8 to 14 kg NH_4-N ha^{-1}).

2.4.3 Plant Development and Biomass Accumulation

Early season nodal development of soybean (Tables 2-12 and 2-13) was influenced by treatments within each site-year and biomass was only affected in 2012 (Tables 2-12 and 2-14). At Russiaville at R2, soybean developed more main-stem nodes (0.5 to 1.1 per plant) with the high rate of manure (431 kg N ha^{-1} applied) compared to all other treatments. At Farmland, soybean developed 0.5 to 1 extra node per plant at R2 for all three manure rates (116 to 231 kg N ha^{-1} applied) and the low and medium UAN rates (168 and 336 kg N ha^{-1} applied) when compared to the UTC. The high rate of UAN did not differ from the UTC, which averaged six nodes per plant. By R6, treatments did not differ at Russiaville and Farmland and soybean averaged 11 nodes per plant. By R6 at Farmersburg, the UTC and all UAN rates produced up to 1.7 more nodes per plant than the low and high manure rates (358 and 597 kg N ha^{-1} applied). At Fort Branch, soybean amended with low and medium rates of manure (229 to 399 kg N ha^{-1} applied) and the high UAN rate produced more nodes (1.1 to 1.7 nodes per plant) than the UTC at R2. Soybean nodal differences were transient and did not differ by R6. The high rates of manure (~600 kg N ha^{-1} applied) in 2013 trials damaged soybean development, which hampered nodal development (Table 2-13).

Early season biomass only differed among treatments in 2012, and R6 biomass was generally not affected across site-years (Tables 2-12 and 2-14). At Farmland at R2, soybean treated with low and high rates of manure (116 and 231 kg N ha^{-1} applied) accumulated 261 to 750 kg ha^{-1} more biomass than the UAN rates and the UTC (Table 2-14). Soybean treated with medium to high rates of UAN sustained stand loss from seedling injury (i.e., “burn”), and thus produced less biomass than UTC (Tables 2-13 and 2-14). Plant population for the UTC was 345,500 plants ha^{-1} compared to the high and medium UAN rates which were 237,900 and 260,500 plants ha^{-1}, respectively (Table 2-13). The only treatment at Farmland that produced more biomass than the UTC at R6 was the high manure rate (5635 vs. 3532 kg ha^{-1}), and the other six treatments did not differ from one another.

At Russiaville, the effects of manure on R2 biomass were not consistent, but soybean treated with a high rate of manure (431 kg N ha^{-1} applied) produced more biomass than the UTC (1324 vs. 952 kg ha^{-1}). Up to 133,000 plants ha^{-1} more were present at R2 for the UTC when compared to the manure treatments, so the increase in biomass of manure-treated soybean was a result of larger plants. Soybean did not emerge in the manure injection bands and thus, plant population was lower in manure-amended areas. All three manure rates had lower populations than the UTC (330,800 to 368,800 vs.

463,600 plants ha^{-1}). Also, the high and medium UAN treatments had 64,000 and 92,000 fewer plants than the UTC, respectively. By R6 at Russiaville, the UTC had the highest plant stand among all treatments at 439,900 plants ha^{-1} (Table 2-13).

Similar findings are reported by studies in Ohio and Minnesota. In Ohio, injecting swine manure at 67, 134, and 202 kg N ha^{-1} before planting full-season soybean resulted in more early season biomass (V4) than the UTC and a linear increase in biomass was observed with N rate. Treatment effects diminished as the season progressed and manure injection did not affect R1 biomass compared to the UTC (Mullen et al., 2008). Stressful growing conditions, especially limited water supply and high temperatures, can severely affect nodulation and biological N fixation. Thus, N applications in 2012 likely alleviated some of those negative effects in our study.

Soybean biomass production did not differ in 2013 at Farmersburg and Fort Branch at either sampling time (Table 2-12). Farmersburg biomass averaged 1560 and 7200 kg ha^{-1} at R2 and R6, respectively. Fort Branch biomass averaged 2140 and 9300 kg ha^{-1} at R2 and R6, respectively. In a Minnesota study, liquid swine manure also did not affect full-season soybean R6 biomass when compared to the untreated control, with no early season data reported (Schmidt et al., 2000). Plant stand in 2013 only differed ($p<0.10$) at R2 at Farmersburg where the medium rate of manure (412 kg N ha^{-1} applied) had approximately 100,000 more plants ha^{-1} than the medium and high rates of UAN (Table 2-13). No treatments differed from the UTC (295,000 plants ha^{-1}).

2.4.4 Grain Yield

Grain yield was positively affected by manure at Russiaville, negatively affected at Farmersburg, and not affected at Fort Branch (Table 2-12, Figure 2-1). Several early fall freezes compromised seed fill and final yields at Farmland in 2012, and thus were not analyzed. Yield increased in conjunction with increased manure rate at Russiaville, and all manure and UAN treatments yielded greater than the UTC (Figure 2-1A). Severe heat and drought existed early in the season and a severe freeze occurred later. This made for an overall stressful environment for double-crop soybean, and N additions helped in this situation. Yields, however, were relatively low at Russiaville (1249 to 1764 kg ha^{-1}) due to a severe freeze at the end of seed fill (~ R6 to R7). This relates to a shorter growing season in 2012 due to the northern latitude of research locations and slower soybean development due to drought. Schmidt et al. (2001) also reported that full-season soybean yield (2670 to 3270 kg ha^{-1}) increased linearly (1.4 kg kg^{-1} of applied available N from swine manure with a range from 145 to 413 kg N ha^{-1}) in three out of seven Minnesota locations.

Yield at Farmersburg was negatively affected by the application of manure, with the highest yields being obtained by UAN application and the UTC (Figure 2-1B). Under simple regression (2^{nd} order polynomial), yield was maximized at about 170 kg N ha^{-1} (Figure 2-2). An additional tillage pass was required following manure application due to rough soil surface. This additional tillage left the soil loose, and thus it dried out and remained dry through August (well below normal precipitation). Therefore, dry soil conditions may be the driving factor of lower yields from manure plots.

A high yield environment existed at the Fort Branch location in 2013 (3123 to 3460 kg ha^{-1}), and yield did not differ among treatments (Figure 2-1C). Abundant precipitation early and late in the growing season likely favored adequate BNF to supply the N needs in the UTC. At eight site-years in Iowa yielding 2850 to 4390 kg ha^{-1}, liquid swine manure application did not affect full-season soybean yield at the three of eight locations (Woli et al., 2013). Under simple regression (2nd order polynomial), grain yield was maximized between 400 to 450 kg N ha^{-1} at Russiaville in 2012 and Fort Branch in 2013 regardless of N source (Figure 2-2).

2.4.5 Nitrogen Accumulation in Biomass and Grain

Early season (R2) N accumulation differed due to treatments in 2012 (Tables 2-12 and 2-14), but not in 2013. At Russiaville, soybean accumulated more N (~15 kg N ha^{-1}) in the high rates of UAN and manure (431 kg N ha^{-1} applied) than the UTC. At Farmland at R2, soybean accumulated up to 34 kg N ha^{-1} more N in the biomass from manure-amended soils (116 and 231 kg N ha^{-1}) than the UTC and UAN treatments (Table 2-14). All treatments had a greater N concentration at R2 than the UTC except the medium manure rate. Early season accumulation of N did not differ at Farmersburg, but soybean treated with all three manure rates (358 to 597 kg N ha^{-1}) and the two highest UAN rates produced a higher N concentration (3.8 to 4.4%) in R2 biomass than the UTC (3.0%). Of all the site-years, soybean at Fort Branch accumulated the most N by R2 though treatments did not differ there.

At R6, N accumulation only differed at Farmland ($p<0.1$), where soybean treated with a high manure rate (231 kg N ha^{-1} applied) accumulated 61 kg N ha^{-1} more than the

UTC (Table 2-14). Nitrogen accumulation at R6 ranged from 129 to 155 kg N ha^{-1} at Russiaville, 161 to 196 kg N ha^{-1} at Farmersburg, and 172 to 243 kg N ha^{-1} at Fort Branch. Similar swine manure effects on soybean were reported in Minnesota where N accumulation responses were transient. Full-season soybean treated with swine manure accumulated 26% more N early in the season and only 9% more N in R6 biomass when compared to the UTC (Schmitt et al., 2001b).

Grain N removal (Figures 2-1 and 2-3) closely followed yield at Russiaville and Fort Branch because grain N concentrations (Figure A-1) did not differ among treatments and averaged 6.6% and 5.6%, respectively. Grain N concentrations differed ($p<0.1$) at Farmersburg (5.5 to 5.7%), but grain N removal still closely followed yield.

At Russiaville, all treatments removed more N in grain than the UTC. Grain N removal increased 8, 20, and 30 kg N ha^{-1} from the low to high manure rates (187 to 431 kg N ha^{-1} applied) compared to the UTC (Figure 2-1A). At Farmersburg, high manure removed 99 kg N ha^{-1} in grain, which was less than other treatments (119 to 137 kg N ha^{-1}, Figure 2-1B). Soybean removed similar amounts of N in the grain whether treated with the low and medium rates of manure (358 and 412 kg N ha^{-1} applied) or the medium and high rates of UAN (336 and 504 kg N ha^{-1} applied) or not treated at all (Figure 2-1B). All three manure rates had higher grain N concentrations (5.7%) than the UTC (5.5%). Grain N removal showed only numerical differences at Fort Branch with the UTC removing 154 kg N ha^{-1} and other treatments removing 161 to 170 kg N ha^{-1} (Figure 2-1C). Therefore, it appears that although grain yield differences were not observed, the same trends were present at Fort Branch as at Russiaville.

In a few cases at Russiaville and Farmersburg, the decrease in soil N from R2 to post-harvest was roughly equal to the increase in soybean accumulation of N from R2 to grain. The proportion of total N accumulated at R6 that was removed in the grain increased when the medium and high rates of manure (0.73 and 0.66, respectively) were applied at Russiaville as compared to the UTC (0.56). The ratios of grain N removal to total N uptake at R6 did not differ at Farmersburg (0.61 to 0.78) and at Fort Branch (0.70 to 0.95).

Nitrogen balances revealed that more N was recovered in grain at the lower rates of N as compared to higher rates. As N rates increased for manure and UAN, less was recovered in grain (Table 2-15). Interestingly, grain N recovery from manure-amended soils was somewhat similar to the grain N recovery from UAN. Medium to high UAN rates (336 to 504 kg N ha^{-1} applied) recovered 26 to 17% at Russiaville, 39 to 26% at Farmersburg, and 48 to 34% at Fort Branch. Soybean recovered 24% of the high rate of manure (431 kg ha^{-1} applied) at Russiaville, 29% of the medium rate of manure (412 kg ha^{-1} applied) at Farmersburg, and 41% of the medium rate of manure (399 kg ha^{-1} applied) at Fort Branch (Table 2-15). When application rates increased, grain N removal could not increase in equal amounts. Since the extra N was not all removed by grain, then it had to be lost through volatilization, denitrification, or NO_3-N leaching, and some was undoubtedly left in the stover or soil at harvest.

2.4.6 Conclusions

Overall, soybean appeared to have the potential to benefit from N from swine manure in stressful (i.e., limited water and high temperatures) growing seasons such as

2012. Swine manure application increased soybean grain yield in conjunction with increased application rates in 2012 at Russiaville. This increase of yield was preceded by increased biomass accumulation at R2, but N application generally did not affect biomass accumulation at R6. All treatments left more N in the top 60 cm of soil after harvest compared to the UTC, and most of that N was likely lost throughout the following winter. In 2013, effects of swine manure application to soybean were negligible to negative. At Farmersburg, grain yield was negatively affected by manure application, but this could also be due to the additional tillage pass prior to planting. Significant amounts of soil N were also present at Farmersburg after harvest in the manure-amended soils, which likely led to additional NO_3^- leaching over winter. At Fort Branch, biomass, grain yield, grain N removal, and post-harvest soil N content were not affected by swine manure application suggesting less benefit from swine manure in a high-yield environment with adequate moisture.

In general, application of liquid swine manure to double-crop soybean is acceptable at the recommended rate (168 kg PAN ha^{-1}), but this study was not comprehensive enough to conclude that higher application rates are acceptable. Application of swine manure to double-crop soybean in a high-yield environment does not appear to increase soybean yield or N removal, but also does not appear to leave extra N in the top 60 cm of soil. Also, swine manure application to double-crop soybean appears to cause a ‘build-up’ of other nutrients (e.g., P and K), and also may contribute to long-term accumulation of soil organic N. Overall, manure application to double-crop soybean can be a sound manure management option if it can be executed with minimal soil disturbance, and it is especially beneficial for those producers that need to free up manure storage space.

Table 2-1. Growing location, soil classification, previous wheat yield and straw removal, soybean variety, and plot sizes for Russiaville and Farmland in 2012 and Farmersburg and Fort Branch in 2013.

	2012		2013	
	Russiaville	**Farmland**	**Farmersburg**	**Fort Branch**
GPS coordinates	40.41 N, 86.221 W	40.256 N, 85.156 W	39.275 N, 87.413 W	38.2455 N, 87.529 W
Soil Classification	(A) Brookston silty clay loam; (B) Fincastle silt loam; (C) Miami silt loam	(A) Blount silt loam, ground moraine; (B) Pewamo silty clay loam	Iva silt loam	(A) Birds silt loam, (B) Reesville silt loam, (C) Uniontown silt loam
Official Description	(A) fine-loamy, mixed, superactive, mesic Typic Argiaquoll; (B) fine-silty, mixed, superactive, mesic Aeric Epiaqualf; (C) fine-loamy, mixed, active, mesic Oxyaquic Hapludalf	(A) fine, illitic, mesic Aeric Epiaqualf; (B) fine, mixed, active, mesic Typic Argiaquoll	fine-silty, mixed, superactive, mesic Aeric Endoaqualf	(A) fine-silty, mixed, superactive, nonacid, mesic Typic Fluvaquent; (B) fine-silty, mixed, superactive, mesic Aquic Hapludalf; (C) fine-silty, mixed, superactive, mesic Oxyaquic Hapludalf
Wheat yield (kg ha^{-1}) †	5380	4304	5380	6456
Wheat Straw Removal	Yes	No	No	Yes
Soybean Row Spacing (cm)	38	19	38	19
Soybean Variety	N/A	Pioneer 93Y60	Beck's Hybrids 375	Pioneer 94Y21 (non-gmo)
Soybean Maturity	3.5	3.6	3.7	4.2
Planted Plot Size	18.3 m x 121.9 m	9.1 m x 137.2 m	15.2 m x 152.4 m	9.1 m x 100.6 m
Harvested Plot Size	12.2 m x 121.9 m	5.5 m x 137.2 m	9.1 m x 152.4 m	6.1 m x 100.6 m

† Wheat yields were field averages.

Table 2-2. General soil fertility (0 to 20 cm) taken when soybean was R2 (full bloom) in the untreated control plots for Russiaville and Farmland in 2012 and Farmersburg and Fort Branch in 2013.

Soil Fertility	2012		2013	
	Russiaville	**Farmland**	**Farmersburg**	**Fort Branch**
Organic Matter (%) †	2.5	3.5	2.2	2.2
pH ‡	6.3	6.2	6.4	5.9
CEC	13.3	17.2	9.6	9.7
Phosphorus (mg kg^{-1}) §	40	110	72	44
Potassium (mg kg^{-1}) §	117	154	131	175
Magnesium (mg kg^{-1}) §	252	459	141	180
Calcium (mg kg^{-1}) §	1811	2119	1363	1158
Sulfur (mg kg^{-1}) §	12	10	34	6
Zinc (mg kg^{-1}) §	5.5	4.5	6.3	4.1
Manganese (mg kg^{-1}) §	77	27	133	146
Iron (mg kg^{-1}) §	155	269	264	263
Copper (mg kg^{-1}) §	2.5	3.7	3.6	2.1
Soil Nitrogen				
0-30 cm depth				
NH_4-N (mg kg^{-1}) ¶	4.4	NT	3.9	4.7
NO_3-N (mg kg^{-1}) ¶	5.0	NT	2.3	2.9
30-60 cm depth				
NH_4-N (mg kg^{-1}) ¶	2.3	NT	3.1	2.3
NO_3-N (mg kg^{-1}) ¶	1.7	NT	0.5	1.4

NT = not taken due to dry/hard soil conditions

† Loss by ignition test

‡ SMP buffer method

§ Mehlich-III extraction

¶ KCl extraction

Critical levels in Indiana: P = 20 mg kg^{-1}, K = 100-125 mg kg^{-1}, pH = 6.0-6.5

Table 2-3. Manure nutrient characterization based on multiple subsamples taken the day of application at Russiaville and Farmland in 2012 and Farmersburg and Fort Branch in 2013.

Manure		**2012**		**2013**	
	Unit	**Russiaville**	**Farmland**	**Farmersburg**	**Fort Branch**
C:N ratio		3.0 : 1	2.0 : 1	1.7 : 1	3.6 : 1
Moisture	kg 1000L^{-1}	960	981	962	939
Solids	kg 1000L^{-1}	38	18	36	59
Ash @ 550 C	kg 1000L^{-1}	12	8	17	24
Organic Matter †	kg 1000L^{-1}	26	9	19	35
Organic Carbon ‡	kg 1000L^{-1}	15	5	11	20
Nitrogen, Total (TKN)	kg 1000L^{-1}	5.1	2.7	6.4	5.7
Nitrogen, Ammonium (NH_4-N) §	kg 1000L^{-1}	4.1	2.2	5.0	4.0
Nitrogen, Organic (N) ¶	kg 1000L^{-1}	1.1	0.5	1.4	1.7
Nitrogen, Nitrate (NO_3-N)	kg 1000L^{-1}	B/D	B/D	B/D	B/D
Phosphorus # (P_2O_5)	kg 1000L^{-1}	0.57 (1.3)	0.35 (0.8)	0.61 (1.4)	1.27 (2.9)
Potassium # (K_2O)	kg 1000L^{-1}	2.7 (3.2)	2.3 (2.8)	3.7 (4.4)	2.6 (3.1)
Sulfur #	kg 1000L^{-1}	0.4	0.2	0.4	0.4
Magnesium #	kg 1000L^{-1}	0.4	0.2	0.4	0.9
Calcium #	kg 1000L^{-1}	0.6	0.4	0.6	1.3
Sodium #	kg 1000L^{-1}	0.5	0.3	1.1	1.2
Aluminum #	mg L^{-1}	24	14	32	55
Copper #	mg L^{-1}	10	25	13	11
Iron #	mg L^{-1}	55	49	83	161
Manganese #	mg L^{-1}	10	7	20	35
Zinc #	mg L^{-1}	50	82	67	104

B/D = below detection levels
All nutrients are reported on an as received or 'wet' basis
† Loss by ignition test
‡ OM x 0.58
§ MgO distillation
¶ TKN minus NH_4-N
# Nitric and Perchloric acid digestion

Table 2-4. Manure and urea-ammonium nitrate application rates, resulting N application rates, and injection depths at Russiaville and Farmland in 2012 and Farmersburg and Fort Branch in 2013.

Treatments		2012		2013	
		Russiaville	Farmland	Farmersburg	Fort Branch
		Application Rate (L ha^{-1})			
Manure	Low	36500	42100	56100	40200
	Medium	56100	56100	64550	70150
	High	84200	84200	93550	105200
		Resulting N Rates (kg N ha^{-1})			
Manure	Low	187	116	358	229
	Medium	287	154	412	399
	High	431	231	597	599
	UTC	0			
UAN	Low	168			
	Medium	336			
	High	504			
		Injection Depth (cm)			
	Manure	15	15	30	15
	UAN	5	5	5	5

Table 2-5. Manure and urea-ammonium nitrate application dates, soybean planting and harvest dates, and plant and soil sampling dates for Russiaville and Farmland in 2012 and Farmersburg and Fort Branch in 2013.

	2012		2013	
	Russiaville	**Farmland**	**Farmersburg**	**Fort Branch**
UAN Application	25-Jun	28-Jun	12-Jul	7-Jul
Manure Application	25-Jun	28-Jun	12-Jul	8-Jul
Planting	26-Jun	29-Jun	15-Jul	9-Jul
Harvest	2-Nov	7-Nov	13-Nov	10-Nov
R2 plant sampling	8-Aug	21-Aug	27-Aug	20-Aug
R2 soil sampling	15-Aug	NT	27-Aug	20-Aug
R6 plant sampling	1-Oct	8-Oct	8-Oct	30-Sep
Post-harvest soil	7-Nov	19-Nov	19-Nov	12-Nov

NT = not taken due to dry, hard soil conditions

Table 2-6. Mean monthly air temperature, total monthly precipitation, and 30-year averages (1980-2010) at Russiaville and Farmland in 2012 and Farmersburg and Fort Branch in 2013.

	Russiaville		Farmland		Farmersburg		Fort Branch	
	2012	30 yr	2012	30 yr	2013	30 yr	2013	30 yr
Air Temperature	---°C---							
May	19.0	15.9	19.4	15.9	18.4	17.3	18.4	18.3
June	21.6	21.2	21.8	21.1	21.9	22.1	22.2	23.6
July	25.8	22.9	26.2	22.8	22.9	23.9	23.5	25.2
August	21.4	21.9	21.3	21.8	23.1	23.3	23.4	24.6
September	17.5	18.1	17.6	17.9	20.4	19.3	20.8	20.4
October	10.4	11.4	10.7	11.4	12.9	12.9	13.6	13.9
November	3.6	5.0	3.9	5.4	4.3	6.5	4.3	7.3
Precipitation	---mm---							
May	65.8	112.5	125.0	111.8	128.9	123.2	121.4	150.9
June	50.3	110.7	29.2	107.7	292.0	111.0	175.1	99.1
July	101.6	122.2	62.7	121.4	90.8	116.1	125.6	104.4
August	124.7	99.3	113.8	90.2	13.1	74.4	5.6	94.0
September	127.8	87.6	152.4	75.4	38.8	80.0	85.0	93.5
October	120.1	81.8	119.6	74.9	72.3	91.4	179.3	93.5
November	23.4	93.5	25.4	86.1	69.6	101.1	45.2	116.6

Table 2-7. Phosphorus and potassium applied as a result of manure nitrogen rates prior to planting double crop soybean. Soil pH, soil phosphorus, and soil potassium levels based on soil sampled (0 to 20 cm) after harvest at Russiaville in 2012 and Farmersburg and Fort Branch in 2013.

Source	N Rate	Soil pH	P Applied	Post-Harvest Soil P	K Applied	Post-Harvest Soil K
	kg N ha^{-1}		kg P ha^{-1}	mg kg^{-1}	kg K ha^{-1}	mg kg^{-1}
Russiaville 2012						
Manure	187	6.6	21	44	97	148
Manure	287	6.5	32	49	149	164
Manure	431	6.3	48	55	224	184
UTC	0	6.6	0	41	0	144
UAN	168	6.3	0	41	0	147
UAN	336	6.1	0	46	0	142
UAN	504	6.1	0	32	0	113
	SigF	ns		ns		x
	LSD	-		-		33
	CV%	5		31		18
Farmersburg 2013						
Manure	358	6.6	34	85	205	152
Manure	412	6.5	39	97	236	184
Manure	597	6.5	57	93	342	168
UTC	0	6.5	0	76	0	135
UAN	168	6.7	0	84	0	125
UAN	336	7.0	0	92	0	129
UAN	504	6.8	0	91	0	121
	SigF	ns		ns		x
	LSD	-		-		36
	CV%	5		17		17
Fort Branch 2013						
Manure	229	6.3	51	39	103	151
Manure	399	6.1	89	37	181	147
Manure	599	6.2	133	51	271	165
UTC	0	6.3	0	34	0	131
UAN	168	6.1	0	35	0	145
UAN	336	6.1	0	30	0	137
UAN	504	6.1	0	38	0	151
	SigF	ns		**		ns
	LSD	-		6		-
	CV%	3		10		9

Table 2-8. Soil NH_4-N, NO_3-N, and total inorganic N content (kg ha^{-1}) at soybean growth stage R2 (full bloom) in the 0 to 30 and 30 to 60 cm depths at Russiaville in 2012 and Farmersburg and Fort Branch in 2013.

		0 to 30 cm			**30 to 60 cm**		
Source	**Rate**	**NH_4-N**	**NO_3-N**	**Total Inorganic N**	**NH_4-N**	**NO_3-N**	**Total Inorganic N**
	kg N ha^{-1}	-- **kg N ha^{-1}** --					
Russiaville 2012							
Manure	187	15	68*	83*	11	13*	24*
Manure	287	19	90*	110*	12	17*	30*
Manure	431	16	113*	129*	13	16*	29*
Untreated	0	19	21	40	11	8	19
UAN	168	16	59*	75*	10	16*	26*
UAN	336	24	134*	158*	10	22*	32*
UAN	504	55*	231*	285*	12	24*	36*
	SigF	**	**	**	ns	**	**
Farmersburg 2013							
Manure	358	NT	NT	NT	NT	NT	NT
Manure	412	NT	NT	NT	NT	NT	NT
Manure	597	29	214*	242*	14	5*	20
Untreated	0	17	10	27	14	2	16
UAN	168	NT	NT	NT	NT	NT	NT
UAN	336	NT	NT	NT	NT	NT	NT
UAN	504	38	191*	228*	14	8*	23*
	SigF	ns	**	**	ns	**	x
Fort Branch 2013							
Manure	229	24	27	51	10	7	18
Manure	399	38	63*	103*	11	12	24
Manure	599	46	78*	127*	11	12	25
Untreated	0	20	12	33	10	6	17
UAN	168	20	40*	62	12	17	29
UAN	336	62	173*	221*	13	22*	36*
UAN	504	39	177*	212*	12	44*	56*
	SigF	ns	**	**	ns	*	*

NT= Not taken. Modified sampling was executed at Farmersburg.

SigF-- x, *, and ** Represent significance at p= 0.1, 0.05, and 0.01; respectively.

Values in the table that differ from UTC are denoted with an *. Significance is presented in this fashion because the data was transformed for analysis then back-transformed for presentation; therefore no LSD value is available for presentation.

Table 2-9. ANOVA summary for post-harvest soil general fertility (0 to 20 cm) and soil N (0 to 30 and 30 to 60 cm) for Russiaville in 2012 and Farmersburg and Fort Branch in 2013.

	2012		2013	
Post-Harvest	**Russiaville**	**Farmland**	**Farmersburg**	**Fort Branch**
Organic Matter (%) †	*	NT	ns	ns
pH †	ns	NT	ns	ns
CEC †	ns	NT	ns	ns
Phosphorus (mg kg^{-1}) †	ns	NT	ns	**
Potassium (mg kg^{-1}) †	x	NT	x	ns
Magnesium (mg kg^{-1}) †	ns	NT	ns	ns
Calcium (mg kg^{-1}) †	x	NT	ns	ns
Sulfur (mg kg^{-1}) †	**	NT	ns	ns
Zinc (mg kg^{-1}) †	ns	NT	ns	**
Manganese (mg kg^{-1}) †	ns	NT	ns	ns
Iron (mg kg^{-1}) †	ns	NT	*	x
Copper (mg kg^{-1}) †	ns	NT	ns	*
Soil Nitrogen				
0-30 cm depth				
NH_4-N (mg kg^{-1} or kg ha^{-1})	**	NT	ns	ns
NO_3-N (mg kg^{-1} or kg ha^{-1})	**	NT	**	ns
Total inorganic N (mg kg^{-1} or kg ha^{-1})	**	NT	**	ns
30-60 cm depth				
NH_4-N (mg kg^{-1} or kg ha^{-1})	ns	NT	ns	ns
NO_3-N (mg kg^{-1} or kg ha^{-1})	**	NT	**	ns
Total inorganic N (mg kg^{-1} or kg ha^{-1})	**	NT	**	ns

x, *, and ** Represent significance at p= 0.1, 0.05, and 0.01; respectively

† All nutrients reported are in the top 20 cm of soil, except N.

NT = Not taken due to very dry, hard soil conditions at R2 and severe, early freeze before harvest

Table 2-10. Post-harvest sulfur, zinc, iron, and manganese concentrations in the top 20 cm of soil at Russiaville in 2012 and Farmersburg and Fort Branch in 2013.

		Soil Concentrations			
Source	**Rate**	**Sulfur**	**Zinc**	**Iron**	**Manganese**
	kg N ha^{-1}	**--------------------------------mg kg^{-1}--------------------------------**			
Russiaville 2012					
Manure	187	11.0	6.2	146	87
Manure	287	12.3	7.2	141	102
Manure	431	15.0	7.6	152	78
UTC	0	8.5	6.4	169	83
UAN	168	9.0	5.8	172	96
UAN	336	9.5	6.3	163	77
UAN	504	8.3	6.0	146	98
	SigF	**	ns	ns	ns
	LSD	3.6	-	-	-
	CV%	23	20	18	19
Farmersburg 2013					
Manure	358	49.0	7.3	316	107
Manure	412	73.0	7.5	357	102
Manure	597	27.7	7.7	308	117
UTC	0	30.3	6.2	278	98
UAN	168	27.7	7.4	300	102
UAN	336	35.7	7.7	261	105
UAN	504	27.3	6.9	312	97
	SigF	ns	ns	*	ns
	LSD	-	-	50	-
	CV%	84	14	9	12
Fort Branch 2013					
Manure	229	7.0	3.8	256	141
Manure	399	7.3	3.9	234	148
Manure	599	8.0	5.3	249	153
UTC	0	7.0	3.7	218	144
UAN	168	6.7	3.6	207	136
UAN	336	7.0	3.3	210	143
UAN	504	7.3	3.5	224	148
	SigF	ns	**	x	ns
	LSD	-	0.6	29	-
	CV%	14	9	9	8

SigF-- x, *, and ** Represent significance at p= 0.1, 0.05, and 0.01; respectively

Table 2-11. Post-harvest soil NH_4-N, NO_3-N, and total inorganic N content (kg ha^{-1}) in the 0 to 30 and 30 to 60 cm depths at Russiaville in 2012 and Farmersburg and Fort Branch in 2013.

		0 to 30 cm			30 to 60 cm		
Source	**Rate**	**NH_4-N**	**NO_3-N**	**Total Inorganic N**	**NH_4-N**	**NO_3-N**	**Total Inorganic N**
	kg N ha^{-1}	-- **kg ha^{-1}**--					
Russiaville 2012							
Manure	187	10	17	27	6	21*	28*
Manure	287	9	20	30	7	36*	43*
Manure	431	11	37*	49*	8	50*	58*
Untreated	0	9	14	23	8	11	18
UAN	168	12	17	28	8	31*	39*
UAN	336	14*	42*	56*	8	85*	94*
UAN	504	13*	45*	58*	9	108*	117*
	SigF	**	**	**	ns	**	**
Farmersburg 2013							
Manure	358	14	110*	126*	15	45*	60*
Manure	412	14	124*	144*	14	40*	57*
Manure	597	12	201*	213*	13	75*	89*
Untreated	0	15	11	26	13	5	18
UAN	168	15	24	40	13	15*	29
UAN	336	14	67*	83*	13	16*	31
UAN	504	16	159*	175*	13	49*	63*
	SigF	ns	**	**	ns	**	**
Fort Branch 2013							
Manure	229	18	20	38	11	12	25
Manure	399	18	22	41	10.	12	23
Manure	599	17	29	48	10	17	28
Untreated	0	18	15	33	11	7	19
UAN	168	17	16	33	12	8	20
UAN	336	16	18	34	11	13	25
UAN	504	16	38	54	11	24	35
	SigF	ns	ns	ns	ns	ns	ns

SigF-- x, *, and ** Represent significance at p= 0.1, 0.05, and 0.01; respectively

Values in the table that differ from UTC are denoted with an *. Significance is presented in this fashion because the data was transformed for analysis then back-transformed for presentation; therefore no LSD value is available for presentation.

Table 2-12. ANOVA summary for plant data at full bloom (R2) and full seed (R6) and harvest data for Russiaville and Farmland in 2012 and Farmersburg and Fort Branch in 2013.

	2012		2013	
	Russiaville	**Farmland**	**Farmersburg**	**Fort Branch**
R2 Growth Stage				
Biomass (kg ha^{-1})	**	**	ns	ns
Plant size (g plant^{-1})	**	**	ns	**
N concentration (%)	ns	**	**	ns
N accumulation (kg ha^{-1})	*	**	ns	ns
Population (plants ha^{-1})	**	**	x	ns
Nodes per plant	**	x	x	*
R6 Growth Stage				
Biomass (kg ha^{-1})	ns	x	ns	ns
Plant size (g plant^{-1})	**	ns	**	ns
N concentration (%)	x	**	ns	ns
N accumulation (kg ha^{-1})	ns	x	ns	ns
Population (plants ha^{-1})	**	ns	ns	ns
Nodes per plant	ns	*	**	ns
Harvest				
Yield (kg ha^{-1})	**	NT	**	ns
Oil (%)	**	NT	ns	ns
Protein (%)	*	NT	ns	ns
Protein harvested (kg ha^{-1})	**	NT	**	ns
Test Weight	*	NT	*	ns
Seed Weight (g 100 seeds^{-1})	**	NT	ns	ns
Grain N concentration (%)	ns	NT	x	ns
Grain N removal (kg ha^{-1})	**	NT	**	ns
N ratio (N in grain/N at R6)	x	NT	ns	ns

x, *, and ** represent significance at p= 0.1, 0.05, and 0.01; respectively
NT = not taken because severe, early freeze caused negligible yields

Table 2-13. Plant population and nodal development at full bloom (R2) and full seed (R6) growth stages at Russiaville and Farmland in 2012 and Farmersburg and Fort Branch in 2013.

		Population		Nodes	
Source	**Rate**	**R2**	**R6**	**R2**	**R6**
	kg N ha^{-1}	**---------- plants ha^{-1}----------**		**---------- nodes plant^{-1}--------**	
Russiaville 2012					
Manure	187	330,800	378,200	5.2	10.6
Manure	287	368,800	345,900	5.8	11.6
Manure	431	343,700	320,000	6.3	11.2
UTC	0	463,600	439,900	5.2	10.2
UAN	168	431,300	386,100	5.7	11.1
UAN	336	371,700	350,200	5.5	11.2
UAN	504	400,400	341,600	5.7	11.5
	SigF	**	**	**	ns
	LSD	45,800	53,600	0.5	-
	CV%	8	10	6	8
Farmland 2012					
Manure	116	337,500	219,300	6.7	12.0
Manure	154	316,300	257,800	6.6	11.8
Manure	231	358,800	295,000	6.9	11.7
UTC	0	345,500	267,100	6.0	11.0
UAN	168	285,700	199,300	6.7	10.3
UAN	336	260,500	232,600	6.7	11.1
UAN	504	237,900	235,200	6.3	10.4
	SigF	**	ns	x	*
	LSD	53,800	-	0.5	1.2
	CV%	10	16	5	6
Farmersburg 2013					
Manure	358	305,200	319,600	6.1	9.7
Manure	412	350,200	308,100	6.3	10.2
Manure	597	322,400	298,500	5.8	9.4
UTC	0	294,700	294,700	6.1	10.7
UAN	168	319,600	325,300	5.8	10.4
UAN	336	242,100	290,900	6.8	10.8
UAN	504	263,100	248,800	6.3	11.1
	SigF	x	ns	x	**
	LSD	60,200	-	0.5	0.7
	CV%	14	13	6	4
Fort Branch 2013					
Manure	229	317,700	304,300	8.6	14.3
Manure	399	357,800	317,700	8.9	14.0
Manure	599	290,900	333,000	7.2	14.0
UTC	0	330,100	442,000	7.2	14.0
UAN	168	359,800	346,400	7.6	14.8
UAN	336	306,200	292,800	8.1	14.0
UAN	504	309,000	321,500	8.3	14.2
	SigF	ns	ns	*	ns
	LSD	-	-	1.0	-
	CV%	20	22	7	6

SigF-- x, *, and ** Represent significance at p= 0.1, 0.05, and 0.01; respectively

Table 2-14. Plant biomass and N accumulation at full bloom (R2) and full seed (R6) for Russiaville and Farmland in 2012 and Farmersburg and Fort Branch in 2013.

		Biomass		Nitrogen Accumulation	
Source	**Rate**	**R2**	**R6**	**R2**	**R6**
	kg N ha^{-1}	**------------- kg ha^{-1}-------------**		**-------------- kg N ha^{-1}-------------**	
Russiaville 2012					
Manure	187	910	6037	39	134
Manure	287	1150	6013	49	129
Manure	431	1324	6726	53	155
UTC	0	952	5341	37	133
UAN	168	1171	5914	49	142
UAN	336	937	6115	39	145
UAN	504	1148	5720	51	136
	SigF	**	ns	*	ns
	LSD	214	-	11	-
	CV%	13	11	17	13
Farmland 2012					
Manure	116	1202	4730	55	121
Manure	154	1016	4545	44	117
Manure	231	1424	5635	66	139
UTC	0	941	3532	38	78
UAN	168	780	4071	36	115
UAN	336	674	4456	32	133
UAN	504	712	4119	34	118
	SigF	**	x	**	x
	LSD	209	1012	10	32
	CV%	12	16	13	19
Farmersburg 2013					
Manure	358	1365	6309	60	161
Manure	412	1819	7012	74	193
Manure	597	1550	6951	67	163
UTC	0	1357	6958	41	172
UAN	168	1660	7638	57	193
UAN	336	1422	7740	53	171
UAN	504	1766	7762	68	196
	SigF	ns	ns	ns	ns
	LSD	-	-	-	-
	CV%	29	14	27	12
Fort Branch 2013					
Manure	229	2263	8546	85	194
Manure	399	2491	10307	90	228
Manure	599	2020	8652	79	172
UTC	0	1854	9404	58	221
UAN	168	2281	9405	75	203
UAN	336	1942	9120	72	204
UAN	504	2129	9524	86	243
	SigF	ns	ns	ns	ns
	LSD	-	-	-	-
	CV%	22	14	29	15

SigF-- x, *, and ** Represent significance at p= 0.1, 0.05, and 0.01; respectively

Table 2-15. Applied N recovered in grain at Russiaville in 2012 and Farmersburg and Fort Branch in 2013.

Source	Rate	Total N Applied	Post-Harvest Total Inorganic N in Soil 0 to 30 cm	Post-Harvest Total Inorganic N in Soil 30 to 60 cm	Grain N Removal	Applied N in Grain
Russiaville 2012		--------------------- kg N ha^{-1}	------------------------			%
Manure	Low	187	26	27	80	43
	Medium	287	30	43	92	32
	High	431	49	58	101	24
	UTC	0	23	18	72	-
UAN	Low	168	28	39	79	47
	Medium	336	56	94	88	26
	High	504	58	117	84	17
Farmersburg 2013						
Manure	Low	358	126	60	119	33
	Medium	412	144	57	121	29
	High	597	213	89	99	17
	UTC	0	26	18	130	-
UAN	Low	168	40	29	137	82
	Medium	336	83	31	131	39
	High	504	175	63	130	26
Fort Branch 2013						
Manure	Low	229	38	25	164	72
	Medium	399	41	23	164	41
	High	599	48	28	162	27
	UTC	0	33	18	154	-
UAN	Low	168	33	20	163	97
	Medium	336	34	25	161	48
	High	504	54	35	170	34

Farmland data not included due to no R2 soil taken and an early freeze resulting in negligible yields

*Applied N in grain (%) = grain N removal divided by total N applied

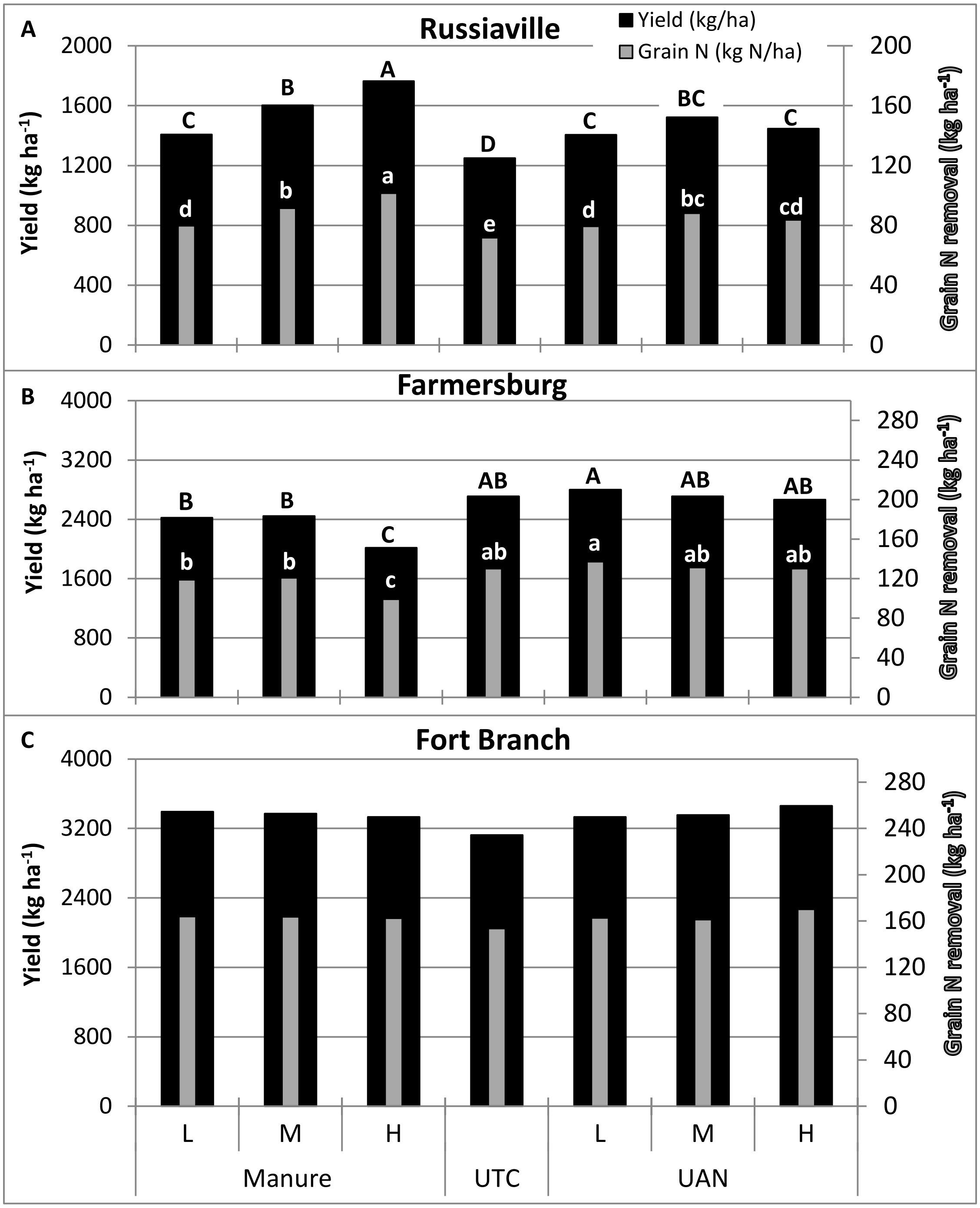

Figure 2-1. Yield (black) and grain N removal (gray) at (A) Russiaville in 2012, (B) Farmersburg in 2013, and (C) Fort Branch in 2013.
Manure rates (kg N ha^{-1}; low, medium, high):
Russiaville: 187, 287, 431. Farmersburg: 358, 412, 597. Fort Branch: 229, 399, 599.

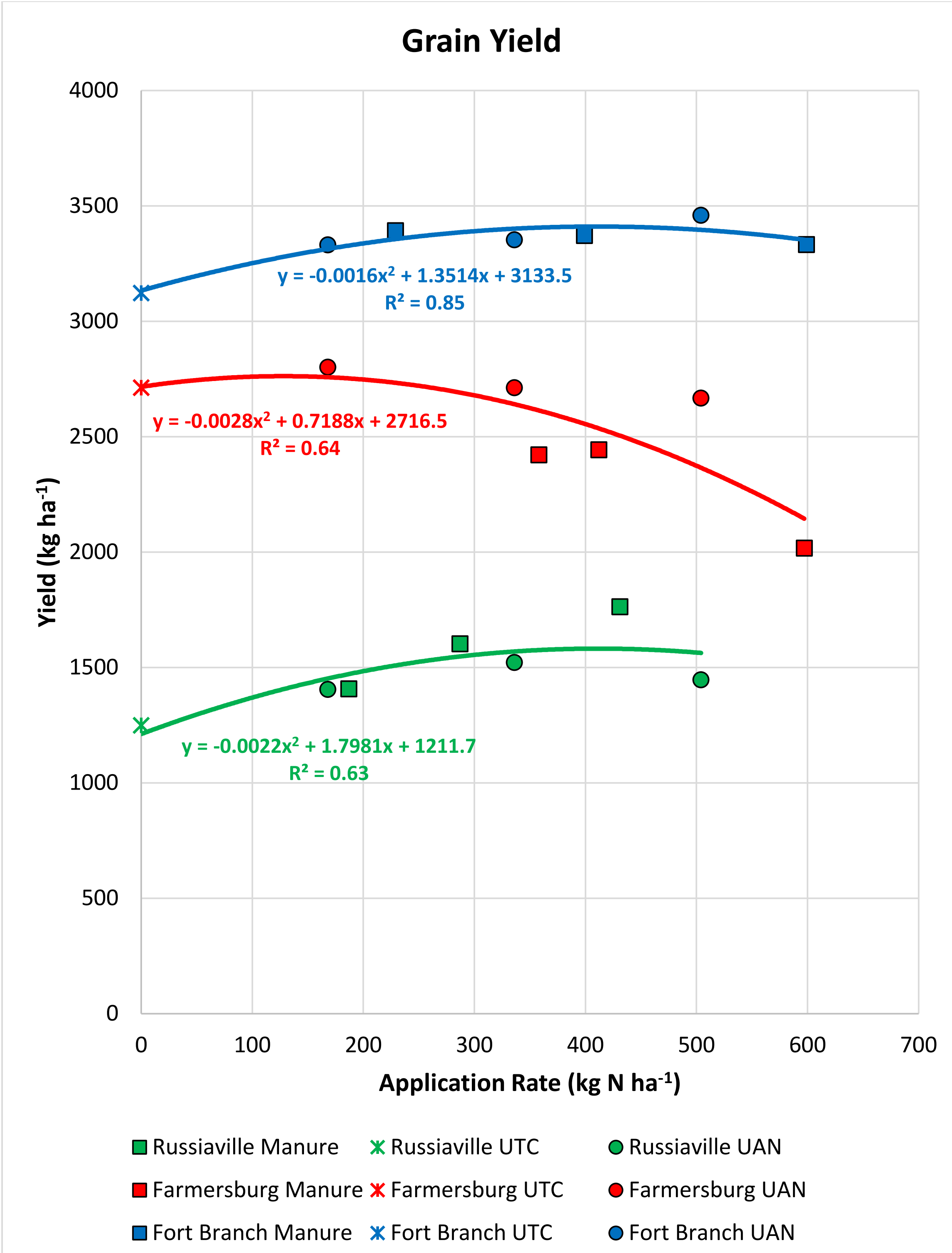

Figure 2-2. Soybean grain yield (kg ha^{-1}) compared to N applied (kg N ha^{-1}) from manure and UAN at Russiaville in 2012 and Farmersburg and Fort Branch in 2013. UTC is the untreated control.

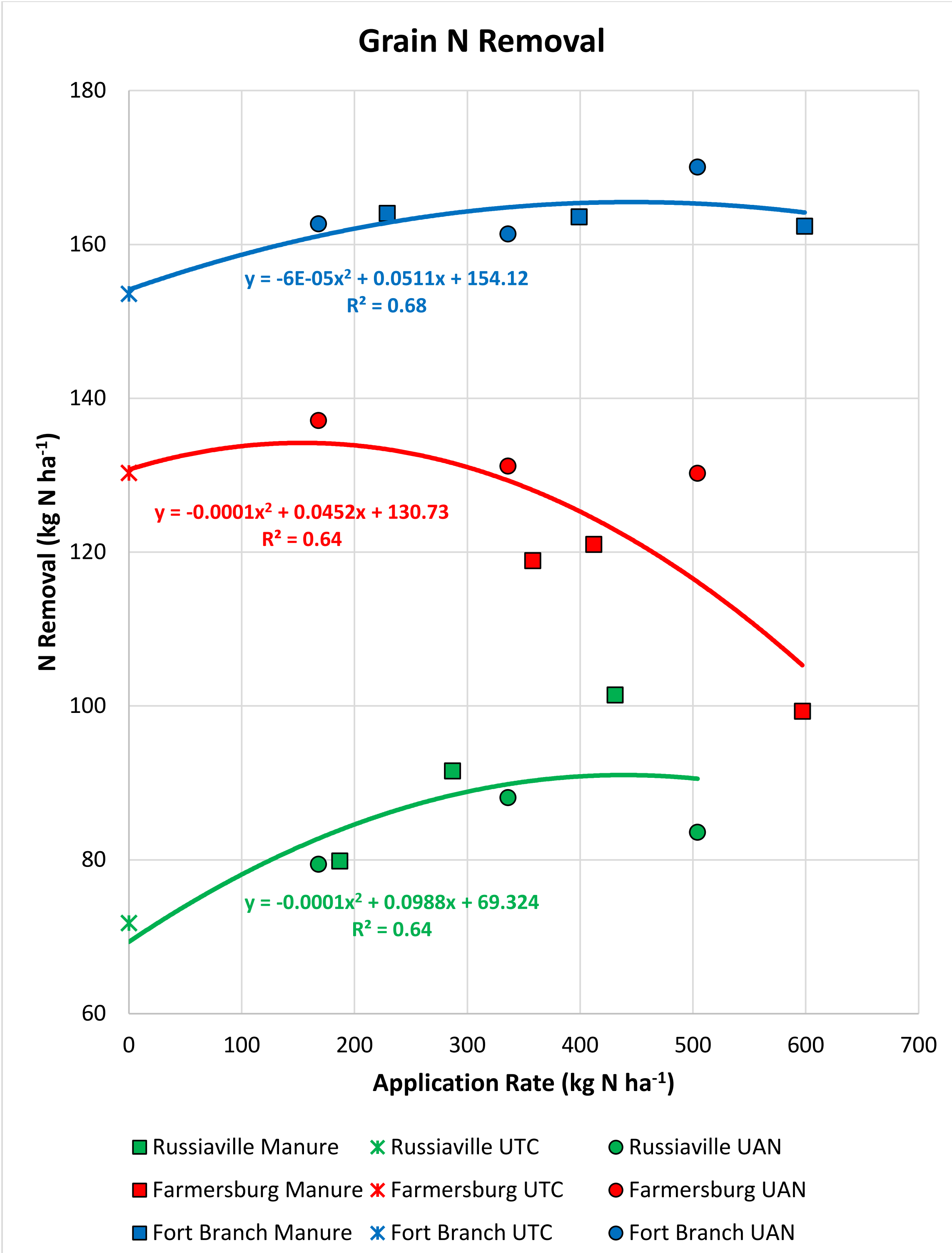

Figure 2-3. Grain N removal (kg N ha^{-1}) compared to N (kg N ha^{-1}) from manure and UAN at Russiaville in 2012 and Farmersburg and Fort Branch in 2013. UTC is the untreated control.

CHAPTER 3. SOIL NITROGEN EFFECTS FROM SWINE MANURE APPLIED TO DOUBLE-CROP SOYBEAN

3.1 Abstract

Animal production, especially swine (*Sus scrofa domesticus*) and poultry has increased in the United States prompting the need to manage the larger volume of manure beyond land applications to supply nitrogen (N) for corn (*Zea mays*) production. The goal of the research was to determine if swine manure applications for double crop soybean (*Glycine max*) following wheat (*Triticum spp.*) can limit manure N loading to the soil and environment under simulated mineralization. Four field-scale trials were initiated in 2012 near Russiaville, IN and Farmland, IN and in 2013 near Farmersburg, IN and Fort Branch, IN. Three rates of swine manure were applied prior to planting double-crop soybean to equal 116 to 599 kg N ha^{-1} depending on location. Fertilizer UAN was also applied at 168, 336, and 504 kg N ha^{-1}, and an untreated control (UTC) was included. Deep soil samples (0 to 30 and 30 to 60 cm) were taken at full bloom (R2, ~6 weeks after application) and post-harvest (~4 to 5 months after application) and incubated at 25˚C and -0.33 bar water content for zero, four, eight, and sixteen (2012) weeks. Manure and UAN increased N levels compared to UTC at sampling time (wk 0), but generally did not affect N release throughout incubation. Differences in N levels between treatments stayed constant throughout incubation suggesting that mineralization was similar across treatments. Applying swine manure to double-crop soybean will produce available N for soybean

to utilize in quantities similar to applying an inorganic fertilizer like UAN at an equivalent N rate. Additional N from swine manure application appears to be present throughout the growing season, including post-harvest if conditions were dry or yield environment was low. This presented a potential for N loss through nitrate leaching during the winter if N.

3.2 Introduction

Immobilization is the conversion of inorganic N to organic N. Immobilization can 'tie up' as much as 76% of ammonium (NH_4-N) in soil following the application of anaerobically treated pig slurry (Bernal and Kirchmann, 1992). In Denmark, most immobilized N remained in the soil after 2 to 3 years following slurry application and contributed to long-term accumulation of soil organic N (Sørensen and Amato, 2002).

Generally, 20 to 80% of the N in animal manure is in the organic form depending on storage methods and feed rations (Beegle et al., 2008). This organic N and any N that was immobilized following manure application can go through mineralization, which is the conversion of organic N to inorganic N (usually NH_4-N). Many factors affect N mineralization in the soil including soil temperature, moisture, and oxygen content (Jenkinson and Wild, 1988).

Mineralization rates in the soil can be affected by the addition of manure. Typically, immobilization occurs first with high rates of mineralization to follow. Then, mineralization of manure-amended soil plateaued to rates comparable to untreated soil (Burger and Venterea, 2008; Kirchmann and Lundvall, 1993).

Alternatively, mineralization rate never differed between untreated soil and soil treated with pig slurry in the United Kingdom (Flowers and Arnold, 1983).

Field experiments were established by amending soil with swine manure and UAN prior to planting double-crop soybean (see Chapter 2). The objectives of this study were (1) to determine the N mineralized from these amended soils under simulated conditions and (2) to identify potentially available N and N loss potential.

3.3 Materials and Methods

3.3.1 Site Characterization

The experiment was conducted at four Indiana locations in 2012 and 2013 (Table 3-1). Early wheat harvest in 2012 enabled the trials to be located in north-central Indiana (Russiaville and Farmland). Success of double-crop soybean after wheat is dependent upon the year for north-central Indiana. Double-crop soybean production is common in southern Indiana, which was the region of the 2013 trials (Farmersburg and Fort Branch). Though, wheat harvest was later than normal in 2013.

Manure was swine slurry from confined finishing barns (Table 3-2). Total Kjeldahl nitrogen (TKN) in manure at Russiaville, Farmland, Farmersburg, and Fort Branch was 5.1, 2.7, 6.4, and 5.7 kg N 1000 L^{-1}, respectively. Manure phosphorus (P) was 1.3, 0.8, 1.4, and 2.9 kg P_2O_5 1000 L^{-1}, respectively by location, and manure potassium (K) 3.2, 2.8, 4.4, and 3.1 kg K_2O 1000 L^{-1}, respectively by location. The resulting N:P:K ratios reported as TKN:P_2O_5:K_2O are 3.9:1:2.5, 3.4:1:3.5, 4.6:1:3.1, and 2.0:1:1.1, respectively for Russiaville, Farmland, Farmersburg, and Fort Branch.

3.3.2 Treatments

Seven treatments were arranged in a randomized complete block design with four replications at Russiaville and three replications at all other sites. Treatments (Table 3-3) were three rates of urea-ammonium nitrate (UAN) (168, 336, and 504 kg N ha^{-1}), three rates of manure (dependent upon location), and one untreated control (UTC) (0 kg N ha^{-1}). Manure and UAN were injected following wheat harvest and prior to planting double-crop soybean. Nitrogen rates using UAN remained constant across site-years to give comparable data. These rates were meant to supply distinct rates of N including a non-limiting supply for soybean. Manure N targets were the same and based on total N supply (not plant available N), but the variable nature of manure and applicator capacities reduced and/or increased the actual manure N applied.

3.3.3 Soil Sampling for Nitrogen

Deep soil samples (0 to 30 and 30 to 60 cm) were taken at R2 (full bloom) and after harvest (within ~1 week) where field conditions were fit (Table 3-4). Extremely dry and hard field conditions during early sampling (R2) prevented sampling at Farmland in 2012 and limited sampling at Farmersburg in 2013. Thus, only soil from the UTC, the high rate of manure, and the high rate of UAN were sampled at R2 at Farmersburg in 2013. Manure and UAN injection bands were taken into account during soil sampling. At Russiaville at R2, a probe tractor was used to collect three sets of subsamples (front, middle, and back of each plot). Five cores were taken within each set of subsamples to total 15 cores per plot. Each subsample set consisted of one core taken directly in the injection band, one core taken on each side 19 cm from the injection band, and one core on each side 38 cm from the injection band. At Farmersburg and Fort Branch at R2, two cores were taken for each of the seven subsample sets throughout the plots. Injection bands were 76 cm on center, so representative sampling was achieved by collecting soil cores that were perpendicular to the injection bands and 38 cm apart. This sampling scheme was also used at all four locations post-harvest. Soil samples were separated into 0 to 30 cm and 30 to 60 cm depths for separate analysis. Soil samples were air-dried in the greenhouse for about a week depending on weather conditions and ground to pass through a 2 mm screen.

3.3.4 Soil Incubation Design and Analysis

Gravimetric soil water content at -0.33 bars of pressure was determined for each soil depth using a pressure plate. A representative sample for each depth and location was achieved by taking a ~50 g subsample of dried and ground soil from each plot from the R2 sampling and thoroughly mixing all subsamples. Each location-depth soil mixture was ran on the pressure plate in triplicate.

Composite samples from each location, sampling time, and depth on a per plot basis were used for incubation. Five grams of dry soil were placed in 50 ml tubes and brought to -0.33 bar water content using double de-ionized water. Soil was incubated at 25° C for zero, four, eight, and sixteen weeks in 2012 and zero, four, and eight weeks in 2013. Field samples were incubated in triplicate in 2012 and in duplicate in

2013. Soils were adjusted to -0.33 bars weekly. The caps of the incubation tubes were not screwed on tight to allow aeration or aerobic conditions.

Incubated soils were extracted for NO_3-N and NH_4-N with a 1:10 ratio of dry soil (5 g) to KCl (50 ml). The soil-KCl mixture was shaken for one hour at 65 rpm oscillation in 250 ml Erlenmeyer flask (McTaggart and Smith, 1993). The mixture was then filtered into 20 ml scintillation vials with Whatman #42 filter paper, then one drop of chloroform was added to each vial to preserve the sample. The soil-KCl extractant was analyzed for nitrate (reported as NO_3-N) and ammonium (reported as NH_4-N) on a Skalar San^{++} Automated Wet Chemistry Continuous Flow Analyzer from Skalar Analytical, The Netherlands.

Nitrate and total inorganic N (NO_3-N + NH_4-N) release rates were calculated by subtracting the previous incubation period from the following incubation period (i.e., wk 4 - wk 0, wk 8 - wk 4, wk 16 - wk 8). Resulting values were divided by the number of weeks between the two incubation periods to determine release rate of nitrate and total inorganic N on a weekly basis. Thus, weekly release rates were used to directly assess differences in NO_3-N and total inorganic N release rates across incubation conditions of the treated soil rather than initial treatment effects. All soil N adjustments were calculated on an individual plot basis. Ammonium was not analyzed in this fashion because all values would be negative due to decreasing NH_4-N during incubation (Figures 3-1 through 3-4).

3.3.5 Statistical Analysis

The resulting NO_3-N and total inorganic N release rates along with the absolute concentrations for weeks 0, 4, 8, and 16 were considered for transformation, but data did not need transformed. Data were subjected to an analysis of variance (ANOVA) in PROC GLM of SAS version 9.3 (SAS Inst., Cary, NC). Means separation was conducted using Fisher's Protected Least Significant Difference at α = 0.05 ($FLSD_{0.05}$). Due to varying rates of manure, site-years were not combined and will be discussed separately.

3.4 <u>Results and Discussion</u>

3.4.1 Early Season Field Sample: Resulting Soil Nitrogen Changes

Early season soil samples were taken while growing soybean was at R2 (full bloom), which was 6 to 7 weeks after the manure and UAN application at Russiaville in 2012 and Farmersburg and Fort Branch in 2013. Due to the short period of time and lack of rainfall to move N down the soil profile, most N and treatment effects were expected to remain in the top 30 cm. Soil N concentrations in the upper 30 cm were influenced by field treatments within the initial sampling (wk 0) and were present after several incubation periods (Table 3-5 and Figures 3-1 through 3-4). Initial NO_3-N, NH_4-N, and total inorganic N concentrations in the upper 30 cm were the greatest from the high rate of UAN (54, 13, and 67 mg kg^{-1}, respectively) at Russiaville in 2012 (Figure 3-1). The remaining treatments did not differ in NH_4-N, but NO_3-N and total inorganic N differed among treatments (Figure 3-1). Manure treatments differed only between the high and low rates at Russiaville in 2012 (Figure

3-1). Nitrate-N and total inorganic N in the upper 30 cm were highest for the medium (48 and 55 mg kg^{-1}, respectively) and high (43 and 52 mg kg^{-1}, respectively) rates of UAN at Fort Branch in 2013 (Figure 3-2). The remaining treatments did not differ ranging from 3 to 20 mg NO_3-N kg^{-1} and from 8 to 31 mg total inorganic N kg^{-1} (Figure 3-2). At Farmersburg (modified sampling, data not shown), NO_3-N and total inorganic N were highest for the high manure (53 and 59 mg kg^{-1}, respectively) and high UAN (44 and 53 mg kg^{-1}, respectively) rates compared to the UTC (2 and 6 mg kg^{-1}, respectively).

Throughout the incubation of early-season soil samples from the upper 30 cm, NO_3-N production outpaced the decrease in NH_4-N to produce more total inorganic N in all locations. No immobilization was observed, and nitrification rates were higher than mineralization rates resulting in very low NH_4-N concentrations at all incubation weeks after the initial period (wk 0). Mineralization rates were typically the greatest in the first incubation sequence (wk 0 to wk 4) and then tended to level off at subsequent weeks at all locations (Tables 3-6 and 3-7; Figures 3-1 and 3-2).

Overall, N concentrations in the lower depth (30 to 60 cm) were less than the upper depth. The lower depth exhibited very few differences in mineralization rates among treatments (Table 3-6 and 3-7), with the exception that initial (wk 0) NO_3-N and total inorganic N were greatest for high UAN at Russiaville in 2012 and at Fort Branch in 2013 (Figures 3-3 and 3-4). The trend in the lower depth was similar to the upper depth in that NO_3-N and total inorganic N increased throughout incubation and NH_4-N decreased. The highest mineralization rates at Fort Branch occurred between wk 0 and wk 4 then leveled off between wk 4 and wk 8 similarly to the upper depth.

Total inorganic N was greater for the high UAN rate (5.1 mg kg^{-1}) than the UTC (3.6 mg kg^{-1}) at Farmersburg in the lower depth at wk 0, and the high manure rate (4.4 mg kg^{-1}) did not differ from either.

Concentrations of NO_3-N and total inorganic N were subtracted from the following week of incubation (i.e. wk 4 – wk 0, wk 8 – wk 4, wk 16 – wk 8) on a per plot basis and then divided by the number of weeks in the incubation period to determine treatment effects on the weekly soil N release rates. Overall, treatments did not affect NO_3-N or total inorganic N release rates in either soil depth throughout incubation periods (Tables 3-6 and 3-7). Treatments did affect total inorganic N release at Russiaville for the first four weeks of incubation in the upper 30 cm (Table 3-7). In the upper 30 cm, high UAN had the lowest total inorganic N release rate over the first four weeks (1.2 mg kg^{-1} wk^{-1}) compared to other treatments (average 3.8 mg kg^{-1} wk^{-1}). Soil amended with the low rate of UAN (168 kg N ha^{-1} applied) released more NO_3-N over the last eight weeks of the incubation (Table 3-6). The remaining treatments did not differ from each other.

At Farmersburg, total inorganic N release rate over four and eight weeks was approximately 4.9 and 3.6 mg kg^{-1} wk^{-1}, respectively in the upper 30 cm regardless of treatment. In the lower 30 cm at Farmersburg, all total inorganic N release rates were below 1 mg kg^{-1} wk^{-1}.

At Fort Branch, treatment effects were not present at either depth beyond the initial values (wk 0) when incubated (Tables 3-6 and 3-7). Total inorganic N release rates over four weeks and eight weeks were greater in the top 30 cm (approximately 7 and 4 mg kg^{-1} wk^{-1}, respectively) than the bottom 30 cm (approximately 2 and 1 mg kg^{-1} wk^{-1}, respectively).

Ammonium N represented 70 to 80% of the total N (TKN) in the manures used. Nitrate was negligible and the organic N in the manure was present in relatively low quantities. The swine manures, low in organic N, were injected in the middle of the summer and these soil samples were taken approximately 45 d after injections. Thus, mineralization, plant uptake, and N loss through volatilization (e.g., 2012) or denitrification (e.g., 2013) were all likely occurring prior to sampling the soil. The combination of these factors could explain why manure or UAN treatments typically did not affect N levels beyond the initial incubation period (wk 0). Others have noted relatively quick and short-term mineralization effects of swine manure amendments to soil. In a 70 d incubation at 25˚C, net N mineralization did not differ after the initial 20 days between UTC and soil amended with anaerobically stored swine manure (Kirchmann and Lundvall, 1993). A similar 180 day study using fresh pig slurry from under confinement barns reported no effect on net N mineralization compared to the UTC after a net N immobilization period of 35 days (Burger and Venterea, 2008).

3.4.2 Post-Harvest Field Sample: Resulting Soil Nitrogen Changes

Treatment effects within post-harvest soil were evident for soil NO_3-N and total inorganic N concentrations in the 30 to 60 cm depth throughout the incubation periods in 2012 and at wk 0 at Farmersburg in 2013 (Table 3-5). In the upper 30 cm at Russiaville, treatments did not differ after wk 0 in NO_3-N and total inorganic N concentrations, and total inorganic N ranged from 24 to 33 mg kg^{-1} at wk 4, 33 to 41 mg kg^{-1} at wk 8, and 42 to 52 mg kg^{-1} at wk 16. Throughout the incubation weeks, total inorganic N concentration was greatest in the lower depth for the high (26 to 31 mg total inorganic N kg^{-1}) and medium (21 to 26 mg total inorganic N kg^{-1}) UAN rates. From wk 4 to wk 16, medium manure (13 to 16 mg total inorganic N kg^{-1}) did not differ from UTC (9 to 13 mg total inorganic N kg^{-1}). The low rate manure-amended soil never differed from UTC in the lower depth. It was very dry in 2012 at Russiaville, but there was some rain late in the season to move N down the soil profile. Therefore, it is likely that N was only moved to the lower 30 cm and not deeper, resulting in higher N levels in the lower depth from N applications.

At Farmersburg, treatments affected NO_3-N and total inorganic N concentrations only at wk 0 of incubation. In the upper 30 cm, total inorganic N concentrations for the high manure (14 mg kg^{-1}) and high (13 mg kg^{-1}) and medium (12 mg kg^{-1}) UAN treatments were greater than other treatments (5 to 7 mg kg^{-1}) at sampling time (wk 0). Total inorganic N concentrations averaged 49 mg kg^{-1} and 57 mg kg^{-1} at wk 4 and wk 8, respectively. In the lower depth, the high (26 mg kg^{-1}) and medium (21 mg kg^{-1}) UAN rate plots contained the greatest total inorganic N concentrations at sampling time (wk 0). Total inorganic N concentrations averaged 14 mg kg^{-1} and 15 mg kg^{-1} at wk 4 and wk 8, respectively. Manure-amended plots yielded lower than other treatments at Farmersburg, therefore there was less plant N uptake and grain N removal, leaving more N in the top 30 cm.

At Fort Branch, post-harvest soil N was not affected by treatment at either depth. In the lower depth, total inorganic N averaged 6, 13, and 15 mg kg^{-1} at wk 0, wk 4, and wk 8, respectively. In the upper 30 cm, total inorganic N averaged 10, 32, and 42 mg kg^{-1} at wk 0, wk 4, and wk 8 respectively. Fort Branch was a high yield environment with large amounts of N uptake. It was also a wet year in 2013 at Fort Branch, so N loss through denitrification and NO_3-N leaching was also likely high. These factors help to explain the limited differences among the manure and UAN treatments and the UTC.

No treatment effects were observed within NO_3-N and total inorganic N release rates (Tables 3-8 and 3-9). At Russiaville, total inorganic N release in the top 30 cm averaged 5, 2, and 1.5 mg kg^{-1} wk^{-1} for the periods 0 to 4, 4 to 8, and 8 to 16 weeks, respectively. In the 30 to 60 cm depth, total inorganic N release averaged 1 mg kg^{-1} wk^{-1} or less for the periods 0 to 4, 4 to 8, and 8 to 16 weeks (Table 3-9).

At Farmersburg, total inorganic N release in the top 30 cm averaged 5 and 2 mg kg^{-1} wk^{-1} for the periods 0 to 4 and 4 to 8 weeks, respectively. In the 30 to 60 cm depth, total inorganic N release averaged 1 mg kg^{-1} wk^{-1} or less for the periods 0 to 4 and 4 to 8 weeks (Table 3-9).

At Fort Branch, total inorganic N release in the top 30 cm averaged 6 and 3 mg kg^{-1} wk^{-1} for the periods 0 to 4 and 4 to 8 weeks, respectively. In the 30 to 60 cm depth, total inorganic N release averaged 2 mg kg^{-1} wk^{-1} or less for the periods 0 to 4 and 4 to 8 weeks (Table 3-9).

No apparent trends were evident among treatments, but N release rates were greater across incubation periods in the upper 30 cm as compared to the lower 30 cm at all locations. In general, Russiaville, Farmersburg, and Fort Branch performed similarly in N release across incubation periods. More N was released across incubation periods for the post-harvest sampling at Russiaville as compared to the R2 sampling. The opposite was true at Fort Branch, and soil at Farmersburg released similar amounts of N regardless of soil sampling time. Fort Branch was a high yielding environment with plenty of moisture; therefore, N was taken up by the crop and likely lost through NO_3-N leaching both in larger quantities than the other locations.

Immobilization can be up to 75% of applied NH_4-N as anaerobically treated swine manure (50% NH_4-N, 50% organic N) (Bernal and Kirchmann, 1992). The study reported immobilization over the first 10 d and then only a small portion of that N was released by the end of the 60 d incubation. Fresh swine manure in the study (8% NH_4-N, 92% organic N) mineralized linearly after six days of incubation and no apparent immobilization. The manure N in our study was 70 to 80% NH_4-N, so the N mineralization kinetics would be expected to be somewhere in between the two mentioned in the Bernal and Kirchmann study. A 175 d incubation study at 30˚C reported no difference in N mineralization from immobilized N or organic N manure fraction between an UTC and soil treated with fresh pig slurry (58% NH_4-N, 42% organic N). In calculating N mineralization rates, the same study concluded that both the UTC and manure-amended soils had higher rates of N mineralization than soil treated with ammonium sulfate (Flowers and Arnold, 1983). Only 41% of the TKN was in the inorganic form by the end of 12 weeks incubation of soil amended with swine lagoon sludge (25% NH_4-N, 75% organic N), but over half of that inorganic N was released via mineralization. Therefore, 28% of the applied organic N was mineralized in 12 weeks (Moore et al., 2005). In a similar 16 week incubation utilizing swine lagoon sludge (15% NH_4-N, 85% organic N), manure-amended soil released 90 mg kg^{-1} more inorganic N than the UTC, and 21% of the applied organic N was mineralized (King, 1984).

It appears that any mineralization differences occurred prior to our sampling time, and any organic N in the soil at the time of samplings was in a very slow release form that did not cause differing mineralization rates among treatments. This claim is supported by Moore et al. (2005) who stated, "The kinetics of the inorganic N accumulation indicate that most of the N mineralization had occurred after 6 to 8 weeks." This was likely the case in our study as the first soil sampling time did not occur until ~6 weeks after application, so most mineralization was completed prior to sampling.

3.5 Conclusions

Manure and UAN did affect initial (wk 0) soil N concentrations with these treatments often supplying much more N at both sampling times and depths than the UTC. This is likely due to potential mineralization of applied organic N in manure prior to soil sampling, applied inorganic N in manure and UAN, and NO_3-N movement down the soil profile. Though, manure and UAN did not affect N release rates after taking into account initial (wk 0) treatment effects, suggesting mineralization was similar compared to the UTC on soils sampled at both R2 (~6 weeks after application) and post-harvest (~4 to 5 months after application). Differences in N concentrations between treatments stayed constant throughout incubation indicating that mineralization was similar across treatments. Applying swine manure to double-crop soybean will produce available N for soybean to utilize in quantities similar to applying an inorganic fertilizer like UAN at an equivalent N rate. Additional N from swine manure application appears to be present throughout the growing season, including post-harvest if conditions were dry or yield environment was low. This presented a potential for N loss through NO_3-N leaching during the winter.

Table 3-1. Growing location, soil classification, previous wheat yield and straw removal, soybean variety, and plot sizes for Russiaville and Farmland in 2012 and Farmersburg and Fort Branch in 2013.

	2012		2013	
	Russiaville	**Farmland**	**Farmersburg**	**Fort Branch**
GPS coordinates	40.41 N, 86.221 W	40.256 N, 85.156 W	39.275 N, 87.413 W	38.2455 N, 87.529 W
Soil Classification	(A) Brookston silty clay loam; (B) Fincastle silt loam; (C) Miami silt loam	(A) Blount silt loam, ground moraine; (B) Pewamo silty clay loam	Iva silt loam	(A) Birds silt loam, (B) Reesville silt loam, (C) Uniontown silt loam
Official Description	(A) fine-loamy, mixed, superactive, mesic Typic Argiaquoll; (B) fine-silty, mixed, superactive, mesic Aeric Epiaqualf; (C) fine-loamy, mixed, active, mesic Oxyaquic Hapludalf	(A) fine, illitic, mesic Aeric Epiaqualf; (B) fine, mixed, active, mesic Typic Argiaquoll	fine-silty, mixed, superactive, mesic Aeric Endoaqualf	(A) fine-silty, mixed, superactive, nonacid, mesic Typic Fluvaquent; (B) fine-silty, mixed, superactive, mesic Aquic Hapludalf; (C) fine-silty, mixed, superactive, mesic Oxyaquic Hapludalf
Wheat yield (kg ha^{-1}) †	5380	4304	5380	6456
Wheat Straw Removal	Yes	No	No	Yes
Soybean Row Spacing (cm)	38	19	38	19
Soybean Variety	N/A	Pioneer 93Y60	Beck's Hybrids 375	Pioneer 94Y21 (non-gmo)
Soybean Maturity	3.5	3.6	3.7	4.2
Planted Plot Size	18.3 m x 121.9 m	9.1 m x 137.2 m	15.2 m x 152.4 m	9.1 m x 100.6 m
Harvested Plot Size	12.2 m x 121.9 m	5.5 m x 137.2 m	9.1 m x 152.4 m	6.1 m x 100.6 m

† Wheat yields are field averages.

Table 3-2. Manure nutrient characterization based on multiple subsamples taken the day of application at Russiaville and Farmland in 2012 and Farmersburg and Fort Branch in 2013.

Manure		**2012**		**2013**	
	Unit	**Russiaville**	**Farmland**	**Farmersburg**	**Fort Branch**
C:N ratio		3.0 : 1	2.0 : 1	1.7 : 1	3.6 : 1
Moisture	kg $1000L^{-1}$	960	981	962	939
Solids	kg $1000L^{-1}$	38	18	36	59
Ash @ 550 C	kg $1000L^{-1}$	12	8	17	24
Organic Matter †	kg $1000L^{-1}$	26	9	19	35
Organic Carbon ‡	kg $1000L^{-1}$	15	5	11	20
Nitrogen, Total (TKN)	kg $1000L^{-1}$	5.1	2.7	6.4	5.7
Nitrogen, Ammonium (NH_4-N) §	kg $1000L^{-1}$	4.1	2.2	5.0	4.0
Nitrogen, Organic (N) ¶	kg $1000L^{-1}$	1.1	0.5	1.4	1.7
Nitrogen, Nitrate (NO_3-N)	kg $1000L^{-1}$	B/D	B/D	B/D	B/D
Phosphorus # (P_2O_5)	kg $1000L^{-1}$	0.57 (1.3)	0.35 (0.8)	0.61 (1.4)	1.27 (2.9)
Potassium # (K_2O)	kg $1000L^{-1}$	2.7 (3.2)	2.3 (2.8)	3.7 (4.4)	2.6 (3.1)
Sulfur #	kg $1000L^{-1}$	0.4	0.2	0.4	0.4
Magnesium #	kg $1000L^{-1}$	0.4	0.2	0.4	0.9
Calcium #	kg $1000L^{-1}$	0.6	0.4	0.6	1.3
Sodium #	kg $1000L^{-1}$	0.5	0.3	1.1	1.2
Aluminum #	mg L^{-1}	24	14	32	55
Copper #	mg L^{-1}	10	25	13	11
Iron #	mg L^{-1}	55	49	83	161
Manganese #	mg L^{-1}	10	7	20	35
Zinc #	mg L^{-1}	50	82	67	104

B/D = below detection levels

All nutrients are reported on an as received or 'wet' basis

† Loss by ignition test

‡ OM x 0.58

§ MgO distillation

¶ TKN minus NH_4-N

Nitric and Perchloric acid digestion

Table 3-3. Manure and urea-ammonium nitrate application rates, resulting N application rates, and injection depths at Russiaville and Farmland in 2012 and Farmersburg and Fort Branch in 2013.

Treatments		**2012**		**2013**	
		Russiaville	**Farmland**	**Farmersburg**	**Fort Branch**
		Application Rate (L ha^{-1})			
Manure	**Low**	36500	42100	56100	40200
	Medium	56100	56100	64550	70150
	High	84200	84200	93550	105200
		Resulting N Rates (kg ha^{-1})			
Manure	**Low**	187	116	358	229
	Medium	287	154	412	399
	High	431	231	597	599
	UTC	0			
UAN	**Low**	168			
	Medium	336			
	High	504			
		Injection Depth (cm)			
	Manure	15	15	30	15
	UAN	5	5	5	5

Table 3-4. Manure and urea-ammonium nitrate application dates, soybean planting and harvest dates, and plant and soil sampling dates for Russiaville and Farmland in 2012 and Farmersburg and Fort Branch in 2013.

	2012		2013	
	Russiaville	**Farmland**	**Farmersburg**	**Fort Branch**
UAN Application	25-Jun	28-Jun	12-Jul	7-Jul
Manure Application	25-Jun	28-Jun	12-Jul	8-Jul
Planting	26-Jun	29-Jun	15-Jul	9-Jul
Harvest	2-Nov	7-Nov	13-Nov	10-Nov
R2 plant sampling	8-Aug	21-Aug	27-Aug	20-Aug
R2 soil sampling	15-Aug	NT	27-Aug	20-Aug
R6 plant sampling	1-Oct	8-Oct	8-Oct	30-Sep
Post-harvest soil	7-Nov	19-Nov	19-Nov	12-Nov

NT = not taken due to dry/hard soil conditions

Table 3-5. ANOVA summary on soil concentrations (NH_4-N, NO_3-N, and Total inorganic N) for all weeks of incubation (0, 4, 8, and 16) at Russiaville and Farmland in 2012 and Farmersburg and Fort Branch in 2013.

		Russiaville 2012				**Farmland 2012**				**Farmersburg 2013**				**Fort Branch 2013**			
	Sampling Time	**R2**		**Post-Harvest**		**R2**		**Post-Harvest**		**R2**		**Post-Harvest**		**R2**		**Post-Harvest**	
	Depth (cm)	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60
	NH_4-N																
Week	0	**	ns	**	ns	NT	NT	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	4	ns	ns	ns	ns	NT	NT	ns	ns	ns	ns	ns	*	ns	ns	ns	ns
	8	ns	ns	ns	ns	NT	NT	ns	ns	ns	*	ns	ns	ns	ns	**	ns
	16	ns	ns	ns	ns	NT	NT	ns	ns	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	NO_3-N																
Week	0	**	ns	**	**	NT	NT	ns	**	*	*	*	*	*	*	ns	ns
	4	**	ns	ns	**	NT	NT	ns	**	*	ns	ns	ns	ns	ns	ns	ns
	8	**	ns	ns	**	NT	NT	ns	**	*	ns	ns	ns	ns	ns	ns	ns
	16	**	ns	ns	**	NT	NT	ns	*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Total inorganic N																
Week	0	**	**	**	**	NT	NT	ns	**	*	ns	*	*	*	*	ns	ns
	4	**	ns	ns	**	NT	NT	ns	**	*	ns	ns	ns	ns	ns	ns	ns
	8	**	ns	ns	**	NT	NT	ns	**	*	ns	ns	ns	ns	ns	ns	ns
	16	**	ns	ns	**	NT	NT	ns	*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

* and ** Represent significance at α= 0.05 and 0.01; respectively

NT = Not taken due to dry, hard soil conditions

Table 3-6. Rates of NO_3-N formed from soil taken during early season (R2) at depths of 0 to 30 and 30 to 60 cm. Soil from Russiaville in 2012 was incubated for 0, 4, 8, and 16 weeks. Soil from Farmersburg and Fort Branch in 2013 was incubated for 0, 4, and 8 weeks. Soil was amended with swine manure, urea-ammonium nitrate, or nothing (UTC) prior to planting double-crop soybean in both years.

			N Release Within Weeks:				N Release Within Weeks:		
		Initial (wk 0)	**0 to 4**	**4 to 8**	**8 to 16**	**Initial (wk 0)**	**0 to 4**	**4 to 8**	**8 to 16**
Source	**Rate**	**0 to 30 cm**				**30 to 60 cm**			
	kg N ha^{-1}	**mg kg^{-1}**	**mg NO_3-N kg^{-1} wk^{-1}**			**mg kg^{-1}**	**mg NO_3-N kg^{-1} wk^{-1}**		
Russiaville 2012									
Manure	187	15.8	4.0	1.7	0.7	2.8	0.2	0.6	0.3
Manure	287	21.4	3.4	2.4	0.8	3.7	0.0	0.5	0.4
Manure	431	26.9	4.1	2.4	0.5	3.7	0.3	0.7	0.4
UTC	0	5.0	5.8	1.7	1.3	1.7	0.2	0.8	0.3
UAN	168	14.2	5.2	2.2	1.2	3.4	0.7	1.4	0.7
UAN	336	31.1	5.1	1.9	0.5	4.9	0.4	1.1	0.5
UAN	504	54.1	3.0	2.6	0.7	5.3	0.1	0.6	0.4
	SigF	**	ns	ns	ns	**	ns	ns	*
	LSD	8.3	-	-	-	1.4	-	-	0.3
Farmersburg 2013									
Manure	358	NT	NT	NT	n/a	NT	NT	NT	n/a
Manure	412	NT	NT	NT	n/a	NT	NT	NT	n/a
Manure	597	52.7	6.4	4.2	n/a	1.3	0.2	0.3	n/a
UTC	0	2.3	6.3	2.9	n/a	0.5	0.2	0.0	n/a
UAN	168	NT	NT	NT	n/a	NT	NT	NT	n/a
UAN	336	NT	NT	NT	n/a	NT	NT	NT	n/a
UAN	504	44.2	6.2	3.8	n/a	2.0	0.2	0.1	n/a
	SigF	**	ns	ns	n/a	**	ns	ns	n/a
	LSD	36.7	-	-	n/a	1.1	-	-	n/a
Fort Branch 2013									
Manure	229	7.2	8.2	3.3	n/a	1.7	2.1	1.0	n/a
Manure	399	15.4	9.8	4.0	n/a	2.8	2.8	0.9	n/a
Manure	599	20.2	9.9	4.8	n/a	3.5	2.3	1.3	n/a
UTC	0	2.9	7.9	3.3	n/a	1.4	2.4	1.0	n/a
UAN	168	10.9	8.1	2.8	n/a	4.4	1.9	0.8	n/a
UAN	336	48.0	9.1	3.7	n/a	6.5	1.7	2.1	n/a
UAN	504	43.0	7.4	3.8	n/a	9.9	2.4	1.1	n/a
	SigF	**	ns	ns	n/a	*	ns	ns	n/a
	LSD	29.6	-	-	n/a	5.0	-	-	n/a

SigF-- * and ** Represent significance at p= 0.05 and 0.01; respectively.

NT = not taken, plots were not sampled.

n/a = not available because we did not incubate to 16 weeks in 2013.

Table 3-7. Rates of total inorganic N formed from soil taken during early season (R2) at depths of 0 to 30 and 30 to 60 cm. Soil from Russiaville in 2012 was incubated for 0, 4, 8, and 16 weeks. Soil from Farmersburg and Fort Branch in 2013 was incubated for 0, 4, and 8 weeks. Soil was amended with swine manure, urea-ammonium nitrate, or nothing (UTC) prior to planting double-crop soybean in both years.

			N Release Within Weeks:				N Release Within Weeks:		
		Initial (wk 0)	0 to 4	4 to 8	8 to 16	Initial (wk 0)	0 to 4	4 to 8	8 to 16
Source	Rate	0 to 30 cm				30 to 60 cm			
	kg N ha^{-1}	mg kg^{-1}	mg N kg^{-1} wk^{-1}			mg kg^{-1}	mg N kg^{-1} wk^{-1}		
Russiaville 2012									
Manure	187	19.3	3.3	1.8	0.8	5.2	0.1	0.3	0.3
Manure	287	25.7	3.1	1.7	0.9	6.4	-0.2	0.3	0.4
Manure	431	30.7	3.5	2.2	0.5	6.4	0.0	0.5	0.4
UTC	0	9.4	4.8	1.8	1.3	4.0	0.0	0.5	0.3
UAN	168	17.8	4.5	2.2	1.2	5.6	1.0	0.7	0.7
UAN	336	36.7	3.8	1.9	0.5	7.0	0.4	0.7	0.5
UAN	504	66.7	1.2	1.4	0.7	8.0	-0.2	0.4	0.4
	SigF	**	**	ns	ns	**	ns	ns	ns
	LSD	9.8	1.7	-	-	1.2	-	-	-
Farmersburg 2013									
Manure	358	NT	NT	NT	n/a	NT	NT	NT	n/a
Manure	412	NT	NT	NT	n/a	NT	NT	NT	n/a
Manure	597	59.4	5.0	4.1	n/a	4.4	0.3	0.1	n/a
UTC	0	6.2	5.5	2.9	n/a	3.6	0.5	0.2	n/a
UAN	168	NT	NT	NT	n/a	NT	NT	NT	n/a
UAN	336	NT	NT	NT	n/a	NT	NT	NT	n/a
UAN	504	52.9	4.3	3.7	n/a	5.1	0.4	0.1	n/a
	SigF	**	ns	ns	n/a	ns	ns	ns	n/a
	LSD	43.0	-	-	n/a	-	-	-	n/a
Fort Branch 2013									
Manure	229	12.7	7.1	2.8	n/a	4.0	1.9	0.7	n/a
Manure	399	24.2	7.9	3.9	n/a	5.3	2.4	0.8	n/a
Manure	599	30.9	7.5	4.7	n/a	5.9	2.1	1.0	n/a
UTC	0	7.5	7.0	3.3	n/a	3.7	2.1	0.8	n/a
UAN	168	15.4	7.3	2.6	n/a	6.9	1.5	0.7	n/a
UAN	336	55.0	8.1	3.1	n/a	9.4	1.5	1.8	n/a
UAN	504	52.0	5.9	3.2	n/a	12.5	2.1	0.9	n/a
	SigF	**	ns	ns	n/a	*	ns	ns	n/a
	LSD	31.5	-	-	n/a	5.5	-	-	n/a

SigF-- * and ** Represent significance at p= 0.05 and 0.01; respectively.

NT = not taken, plots were not sampled.

n/a = not available because we did not incubate to 16 weeks in 2013.

Table 3-8. Rates of NO_3-N formed from soil taken post-harvest at depths of 0 to 30 and 30 to 60 cm. Soil from Russiaville in 2012 was incubated for 0, 4, 8, and 16 weeks. Soil from Farmersburg and Fort Branch in 2013 was incubated for 0, 4, and 8 weeks. Soil was amended with swine manure, urea-ammonium nitrate, or nothing (UTC) prior to planting double-crop soybean in both years.

			N Release Within Weeks:				N Release Within Weeks:		
		Initial (wk 0)	**0 to 4**	**4 to 8**	**8 to 16**	**Initial (wk 0)**	**0 to 4**	**4 to 8**	**8 to 16**
Source	**Rate**	**0 to 30 cm**				**30 to 60 cm**			
	kg N ha^{-1}	**mg kg^{-1}**	**mg NO_3-N kg^{-1} wk^{-1}**			**mg kg^{-1}**	**mg NO_3-N kg^{-1} wk^{-1}**		
Russiaville 2012									
Manure	187	4.0	5.0	1.9	1.2	4.7	1.2	-0.3	0.6
Manure	287	4.9	5.4	1.7	1.4	8.2	0.9	0.1	0.4
Manure	431	9.2	5.8	1.2	1.7	11.7	0.8	0.2	0.3
UTC	0	3.2	5.8	2.4	1.3	2.3	1.5	-0.3	0.6
UAN	168	3.8	6.1	1.7	1.8	6.7	2.5	0.2	0.6
UAN	336	9.9	5.5	1.3	1.4	18.7	0.8	-0.1	0.5
UAN	504	10.6	5.5	1.8	1.3	24.1	0.8	-0.2	0.4
	SigF	**	ns	ns	ns	**	ns	ns	ns
	LSD	3.1	-	-	-	5.5	-	-	-
Farmersburg 2013									
Manure	358	30.2	5.7	2.3	n/a	10.5	0.5	0.9	n/a
Manure	412	38.7	5.1	2.1	n/a	10.5	0.5	0.5	n/a
Manure	597	48.2	5.4	2.1	n/a	17.5	0.5	0.7	n/a
UTC	0	2.5	6.5	1.4	n/a	1.0	0.8	0.8	n/a
UAN	168	6.0	5.9	1.5	n/a	3.6	0.8	0.5	n/a
UAN	336	17.9	5.5	2.7	n/a	4.1	0.9	0.4	n/a
UAN	504	36.9	5.1	2.3	n/a	13.0	0.4	0.9	n/a
	SigF	**	ns	ns	n/a	**	ns	ns	n/a
	LSD	27.0	-	-	n/a	10.3	-	-	n/a
Fort Branch 2013									
Manure	229	4.6	6.3	3.0	n/a	3.4	2.5	0.6	n/a
Manure	399	5.4	6.3	2.7	n/a	2.8	2.3	0.5	n/a
Manure	599	8.5	6.2	2.4	n/a	4.8	2.1	0.5	n/a
UTC	0	3.5	6.4	2.3	n/a	1.7	2.4	0.5	n/a
UAN	168	3.9	6.1	2.1	n/a	1.7	2.0	0.4	n/a
UAN	336	4.1	6.2	3.0	n/a	3.1	2.3	0.6	n/a
UAN	504	9.3	6.8	2.8	n/a	5.5	2.4	0.7	n/a
	SigF	ns	ns	ns	n/a	ns	ns	ns	n/a
	LSD	-	-	-	n/a	-	-	-	n/a

SigF-- * and ** Represent significance at p= 0.05 and 0.01; respectively.

n/a = not available because we did not incubate to 16 weeks in 2013.

Table 3-9. Rates of total inorganic N formed from soil taken post-harvest at depths of 0 to 30 and 30 to 60 cm. Soil from Russiaville in 2012 was incubated for 0, 4, 8, and 16 weeks. Soil from Farmersburg and Fort Branch in 2013 was incubated for 0, 4, and 8 weeks. Soil was amended with swine manure, urea-ammonium nitrate, or nothing (UTC) prior to planting double-crop soybean in both years.

			N Release Within Weeks:				N Release Within Weeks:		
		Initial (wk 0)	0 to 4	4 to 8	8 to 16	Initial (wk 0)	0 to 4	4 to 8	8 to 16
Source	**Rate**	0 to 30 cm				30 to 60 cm			
	kg N ha^{-1}	mg kg^{-1}	mg N kg^{-1} wk^{-1}			mg kg^{-1}	mg N kg^{-1} wk^{-1}		
Russiaville 2012									
Manure	187	6.2	4.5	2.0	1.2	6.1	1.0	-0.2	0.6
Manure	287	7.0	5.0	1.8	1.4	9.7	0.8	-0.1	0.4
Manure	431	11.7	5.3	1.4	1.7	13.5	0.9	-0.1	0.3
UTC	0	5.3	5.3	2.5	1.3	4.0	1.3	-0.3	0.6
UAN	168	6.5	5.5	1.8	1.8	8.5	2.3	0.1	0.6
UAN	336	13.0	4.9	1.4	1.4	20.5	0.7	-0.3	0.5
UAN	504	13.6	4.9	1.9	1.3	26.0	0.6	-0.1	0.4
	SigF	**	ns	ns	ns	**	ns	ns	ns
	LSD	3.4	-	-	-	5.6	-	-	-
Farmersburg 2013									
Manure	358	33.4	5.1	2.3	n/a	13.9	0.8	0.2	n/a
Manure	412	42.0	4.5	2.1	n/a	13.5	0.5	0.2	n/a
Manure	597	50.9	4.9	2.2	n/a	20.4	0.7	0.1	n/a
UTC	0	5.9	5.9	1.4	n/a	4.0	0.9	0.2	n/a
UAN	168	9.5	5.2	1.5	n/a	6.6	0.7	0.2	n/a
UAN	336	21.0	4.9	2.7	n/a	7.0	0.6	0.2	n/a
UAN	504	40.6	4.4	2.3	n/a	15.9	0.5	0.3	n/a
	SigF	**	ns	ns	n/a	**	ns	ns	n/a
	LSD	27.2	-	-	n/a	10.1	-	-	n/a
Fort Branch 2013									
Manure	229	8.8	5.4	3.0	n/a	5.8	2.1	0.6	n/a
Manure	399	9.5	5.4	2.7	n/a	5.0	1.9	0.5	n/a
Manure	599	12.3	5.5	2.3	n/a	6.9	1.8	0.5	n/a
UTC	0	7.5	5.6	2.2	n/a	4.1	2.0	0.5	n/a
UAN	168	7.8	5.4	2.1	n/a	4.4	1.6	0.4	n/a
UAN	336	7.9	5.5	2.9	n/a	5.6	1.9	0.5	n/a
UAN	504	13.0	6.1	2.8	n/a	7.8	2.0	0.6	n/a
	SigF	ns	ns	ns	n/a	ns	ns	ns	n/a
	LSD	-	-	-	n/a	-	-	-	n/a

SigF-- * and ** Represent significance at p= 0.05 and 0.01; respectively.

n/a = not available because we did not incubate to 16 weeks in 2013.

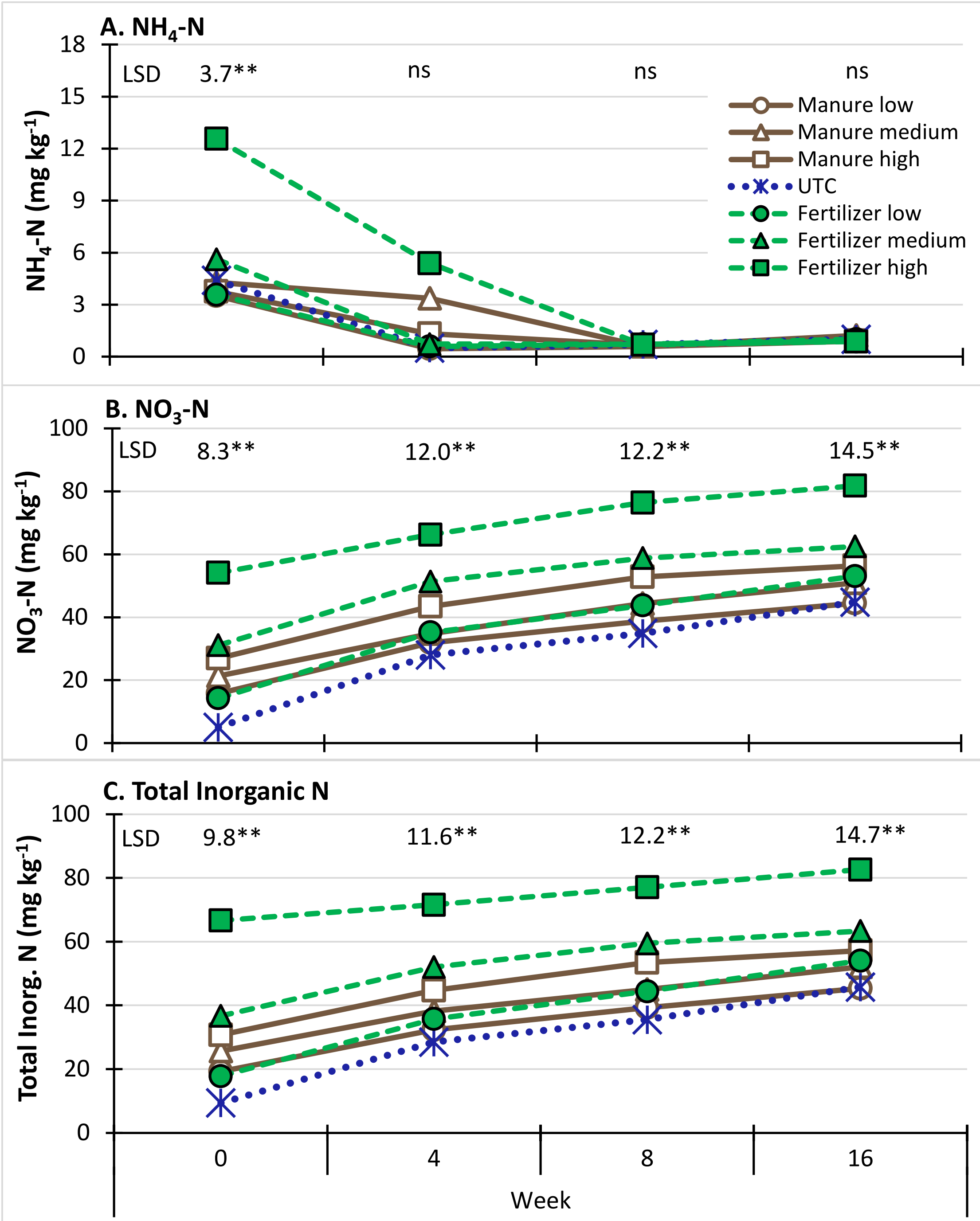

Figure 3-1. Development of (A) NH_4-N, (B) NO_3-N, and (C) total inorganic nitrogen (NH_4-N + NO_3-N) in soil amended with swine manure and fertilizer prior to planting double-crop soybean in Russiaville 2012. Field samples were taken from a soil depth of 0 to 30 cm when soybean was full bloom (~45 d after application) and incubated for 0, 4, 8, and 16 wk. Treatments were separated within incubation period according to Fisher's Protected LSD, which was noted for the respective incubation period. Significance according to ANOVA is represented by * and ** at **α**= 0.05 and 0.01, respectively.

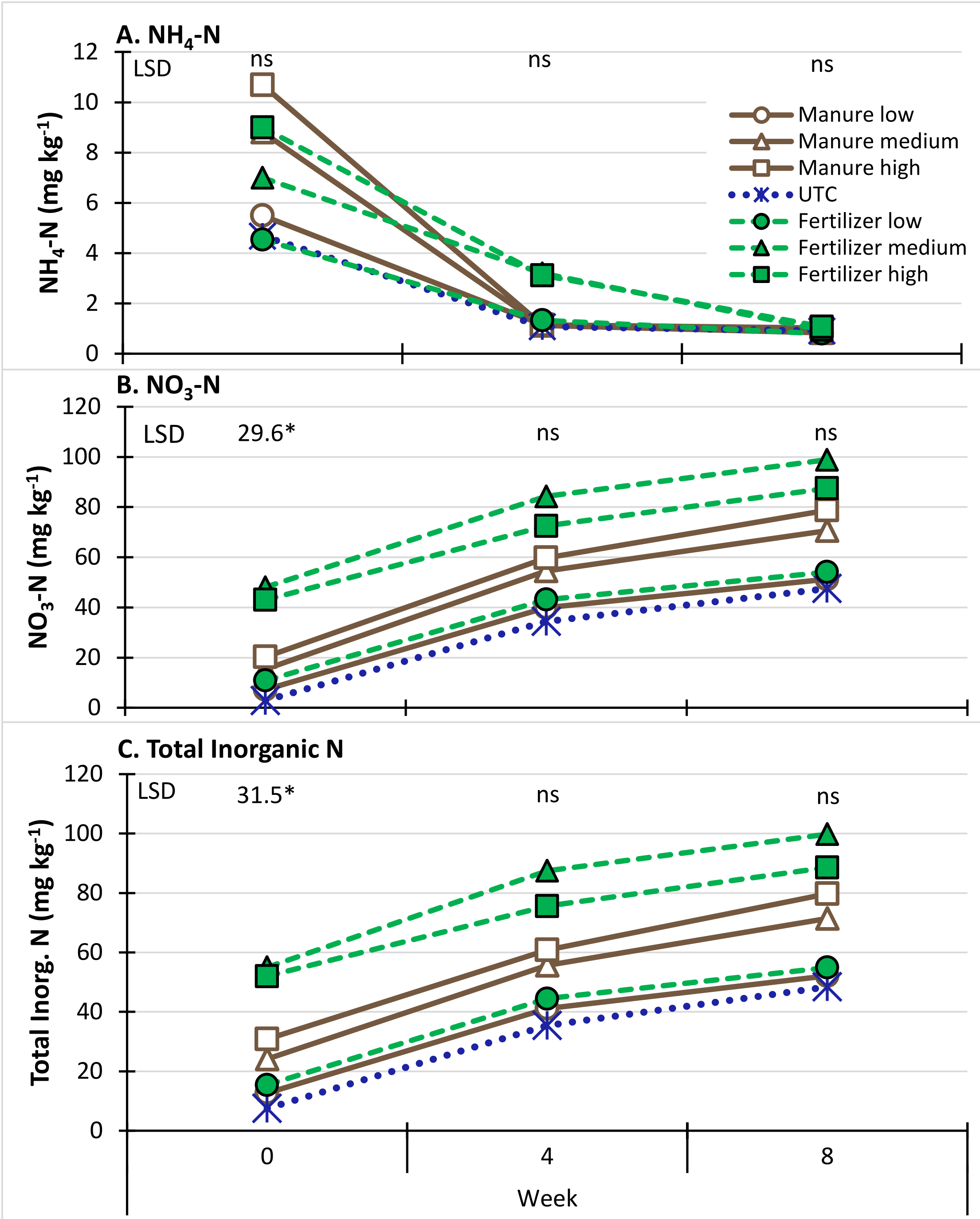

Figure 3-2. Development of (A) NH_4-N, (B) NO_3-N, and (C) total inorganic nitrogen (NH_4-N + NO_3-N) in soil amended with swine manure and fertilizer prior to planting double-crop soybean in Fort Branch 2013. Field samples were taken from a soil depth of 0 to 30 cm when soybean was full bloom (~45 d after application) and incubated for 0, 4, and 8 wk. Treatments were separated within incubation period according to Fisher's Protected LSD, which was noted for the respective incubation period. Significance according to ANOVA is represented by * and ** at **α**= 0.05 and 0.01, respectively.

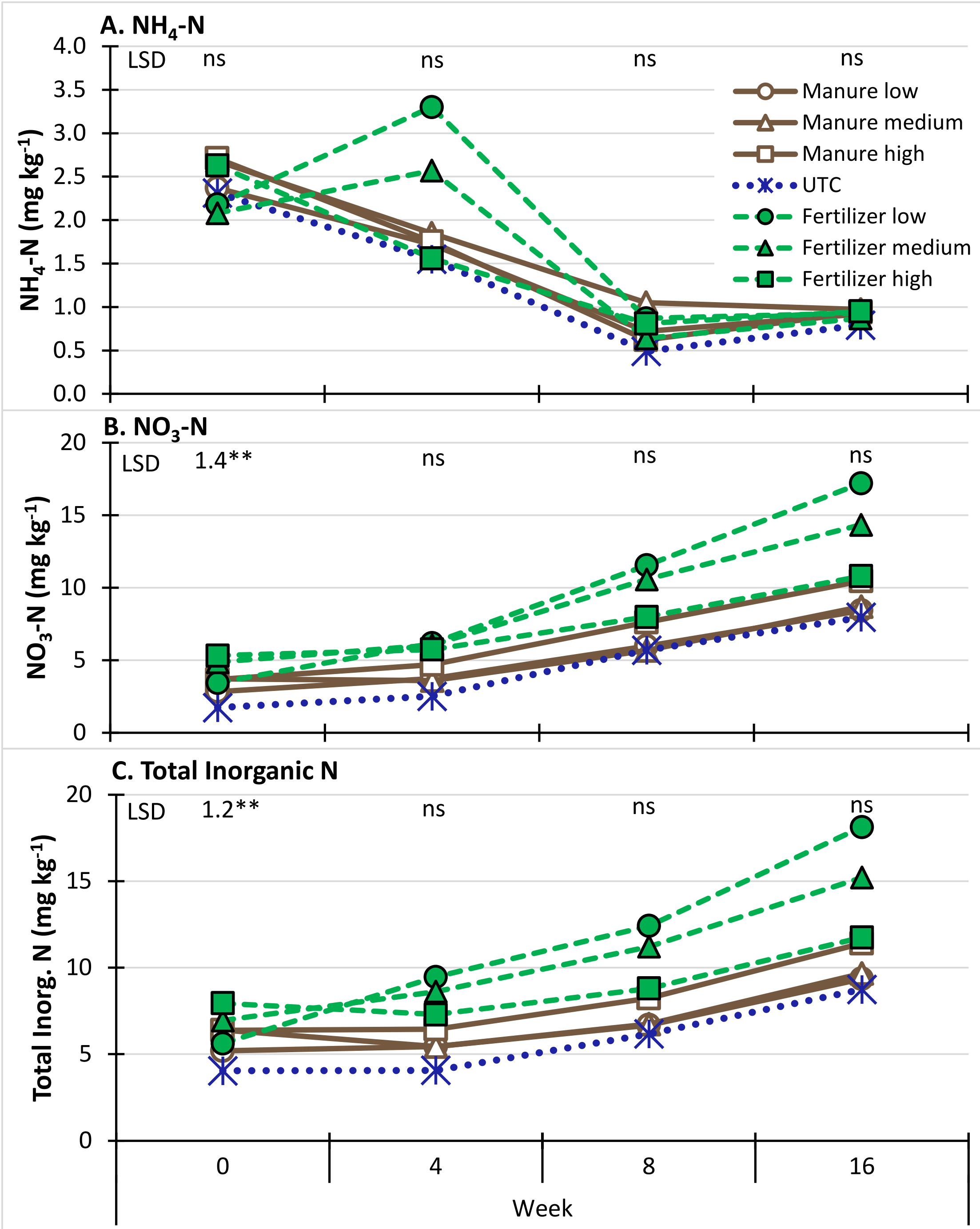

Figure 3-3. Development of (A) NH_4-N, (B) NO_3-N, and (C) total inorganic nitrogen (NH_4-N + NO_3-N) in soil amended with swine manure and fertilizer prior to planting double-crop soybean in Russiaville 2012. Field samples were taken from a soil depth of 30 to 60 cm when soybean was full bloom (~45 d after application) and incubated for 0, 4, 8, and 16 wk. Treatments were separated within incubation period according to Fisher's Protected LSD, which was noted for the respective incubation period. Significance according to ANOVA is represented by * and ** at **α**= 0.05 and 0.01, respectively.

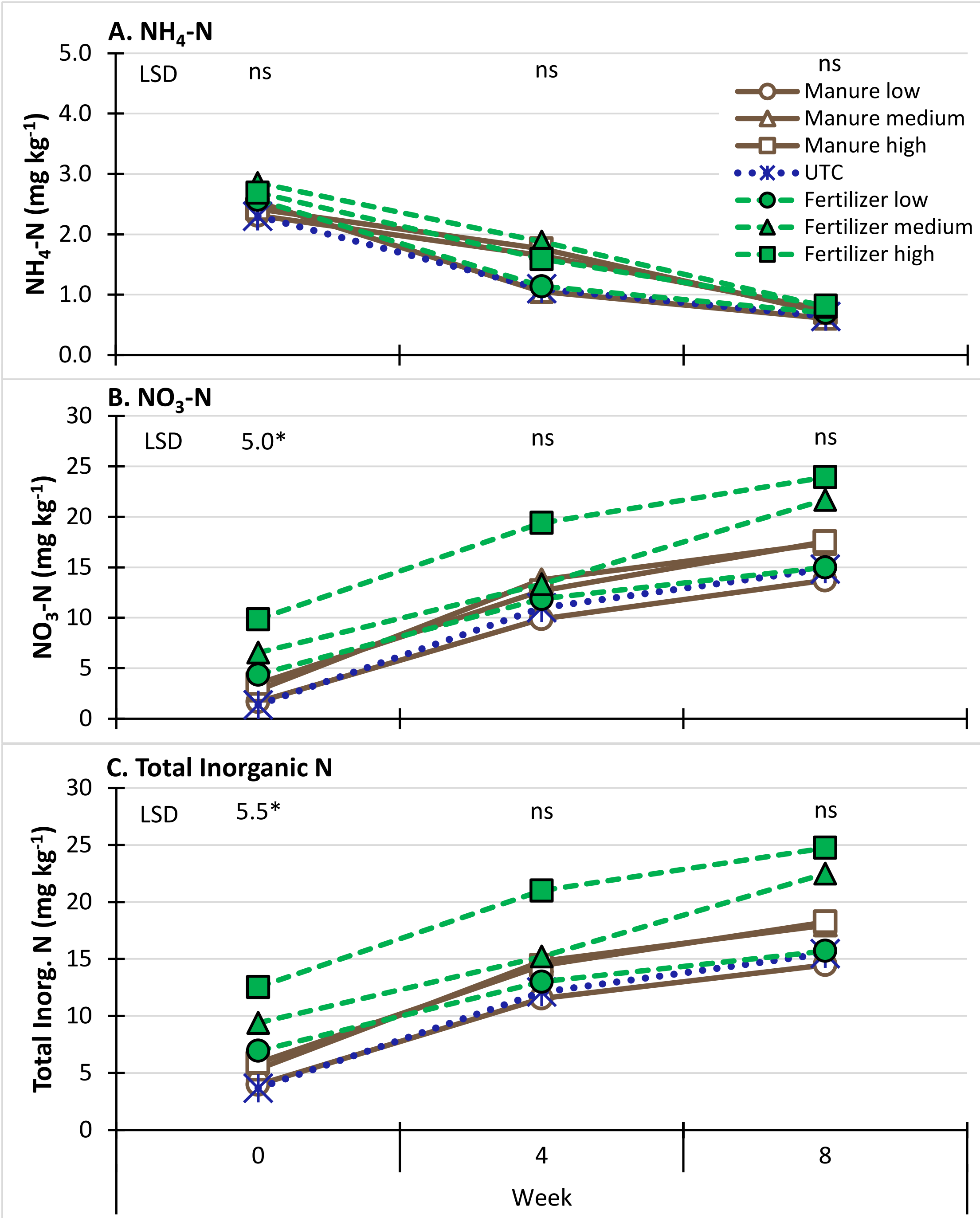

Figure 3-4. Development of (A) NH_4-N, (B) NO_3-N, and (C) total inorganic nitrogen (NH_4-N + NO_3-N) in soil amended with swine manure and fertilizer prior to planting double-crop soybean in Fort Branch 2013. Field samples were taken from a soil depth of 30 to 60 cm when soybean was full bloom (~45 d after application) and incubated for 0, 4, and 8 wk. Treatments were separated within incubation period according to Fisher's Protected LSD, which was noted for the respective incubation period. Significance according to ANOVA is represented by * and ** at **α**= 0.05 and 0.01, respectively.

LITERATURE CITED

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APPENDIX

Table A-1. Soil NH_4-N, NO_3-N, and total inorganic N concentrations (mg kg^{-1}) at soybean growth stage R2 in the 0 to 30 and 30 to 60 cm depths at Russiaville in 2012 and Farmersburg and Fort Branch in 2013.

		0 to 30 cm			30 to 60 cm		
Source	**Rate**	**NH_4-N**	**NO_3-N**	**Total Inorganic N**	**NH_4-N**	**NO_3-N**	**Total Inorganic N**
	kg N ha^{-1}	---mg kg^{-1}---					
Russiaville 2012							
Manure	187	3.5	15.7*	19.1*	2.4	2.8*	5.2*
Manure	287	4.3	20.6*	25.2*	2.7	3.7*	6.4*
Manure	431	3.8	26.1*	29.8*	2.7	3.5*	6.4*
Untreated	0	4.4	4.9	9.3	2.3	1.7	4.0
UAN	168	3.6	13.5*	17.4*	2.2	3.4*	5.5*
UAN	336	5.6	30.8*	36.4*	2.1	4.8*	6.9*
UAN	504	12.6*	53.3*	65.8*	2.6	5.1*	7.8*
	SigF	**	**	**	ns	**	**
Farmersburg 2013							
Manure	358	NT	NT	NT	NT	NT	NT
Manure	412	NT	NT	NT	NT	NT	NT
Manure	597	6.7	49.1*	55.5*	3.1	1.2*	4.4
Untreated	0	3.9	2.3	6.2	3.1	0.5	3.6
UAN	168	NT	NT	NT	NT	NT	NT
UAN	336	NT	NT	NT	NT	NT	NT
UAN	504	8.7	44.0*	52.4*	3.1	1.8*	5.0*
	SigF	ns	**	**	ns	**	x
Fort Branch 2013							
Manure	229	5.5	6.2	11.8	2.3	1.6	4.0
Manure	399	8.8	14.5*	23.9*	2.5	2.7	5.3
Manure	599	10.7	18.0*	29.4*	2.4	2.6	5.5
Untreated	0	4.7	2.8	7.5	2.3	1.3	3.7
UAN	168	4.5	9.3*	14.4	2.6	3.7	6.4
UAN	336	14.4	40.0*	51.1*	2.9	4.8*	7.9*
UAN	504	9.0	40.9*	49.1*	2.7	9.8*	12.5*
	SigF	ns	**	**	ns	*	*

NT= Not taken. Modified sampling was executed at Farmersburg.

SigF-- x, *, and ** Represent significance at p= 0.1, 0.05, and 0.01; respectively

Values in the table that differ from UTC are denoted with an *. Significance is presented in this fashion because the data was transformed for analysis then back-transformed for presentation; therefore no LSD value is available for presentation.

Table A-2. Post-harvest soil NH_4-N, NO_3-N, and total inorganic N concentrations (mg kg^{-1}) in the 0 to 30 and 30 to 60 cm depths at Russiaville in 2012 and Farmersburg and Fort Branch in 2013.

		0 to 30 cm			30 to 60 cm		
Source	**Rate**	**NH_4-N**	**NO_3-N**	**Total Inorganic N**	**NH_4-N**	**NO_3-N**	**Total Inorganic N**
	kg N ha^{-1}	----------	----------	----------mg kg^{-1}	----------	----------	----------
Russiaville 2012							
Manure	187	2.2	3.9	6.1	1.3	4.6*	6.0*
Manure	287	2.1	4.7	6.9	1.6	7.7*	9.3*
Manure	431	2.5	8.6*	11.2*	1.8	10.8*	12.6*
Untreated	0	2.1	3.2	5.3	1.7	2.3	4.0
UAN	168	2.7	3.8	6.5	1.7	6.7*	8.4*
UAN	336	3.1*	9.7*	12.9*	1.8	18.5*	20.3*
UAN	504	3.0*	10.3*	13.3*	1.9	23.3*	25.3*
	SigF	**	**	**	ns	**	**
Farmersburg 2013							
Manure	358	3.2	25.2*	29.0*	3.4	9.9*	13.4*
Manure	412	3.3	28.5*	33.1*	3.0	8.8*	12.7*
Manure	597	2.8	46.1*	49.0*	2.9	16.6*	19.8*
Untreated	0	3.4	2.5	5.9	2.9	1.0	3.9
UAN	168	3.4	5.6	9.2	3.0	3.3*	6.4
UAN	336	3.1	15.4*	19.1*	2.8	3.5*	6.8
UAN	504	3.6	36.6*	40.2*	2.9	10.9*	14.0*
	SigF	ns	**	**	ns	**	**
Fort Branch 2013							
Manure	229	4.2	4.6	8.8	2.5	2.7	5.5
Manure	399	4.2	5.1	9.4	2.3	2.7	5.0
Manure	599	3.8	6.8	11.0	2.1	3.7	6.2
Untreated	0	4.1	3.4	7.5	2.4	1.6	4.1
UAN	168	3.8	3.8	7.7	2.7	1.7	4.4
UAN	336	3.8	4.0	7.8	2.5	2.9	5.5
UAN	504	3.7	8.7	12.5	2.4	5.4	7.8
	SigF	ns	ns	ns	ns	ns	ns

SigF-- x, *, and ** Represent significance at p= 0.1, 0.05, and 0.01; respectively

Values in the table that differ from UTC are denoted with an *. Significance is presented in this fashion because the data was transformed for analysis then back-transformed for presentation; therefore no LSD value is available for presentation.

Table A-3. Phosphorus and potassium rates applied along with post-harvest soil phosphorus, potassium, sulfur, zinc, iron, and manganese concentrations in the top 20 cm at Farmland in 2012.

			Phosphorus		Potassium					
Source	**Rate**	**Soil pH**	**Rate Applied**	**Soil level**	**Rate Applied**	**Soil level**	**Sulfur**	**Zinc**	**Iron**	**Manganese**
	kg N ha^{-1}		**kg P ha^{-1}**	**mg kg^{-1}**	**kg K ha^{-1}**	**----------mg kg^{-1}----------**				
Farmland 2012										
Manure	116	6.6	15	91	98	179	9.0	7.2	208	24
Manure	154	6.6	20	79	130	145	8.0	3.7	202	27
Manure	231	6.5	29	93	196	187	8.3	5.3	222	30
UTC	0	6.6	0	112	0	161	7.3	5.1	241	24
UAN	168	6.9	0	79	0	129	7.0	3.9	197	26
UAN	336	6.8	0	84	0	139	7.0	4.2	199	27
UAN	504	6.4	0	95	0	153	7.7	4.5	210	25

Table A-4. Nitrogen followed through the season in soil, biomass, and grain at Russiaville in 2012 and Farmersburg and Fort Branch in 2013.

		R2 Soil N	Post Harvest Soil N	Change in Soil N †	R2 Plant N Accumulation	R6 Plant N Accumulation	Change in N Accumulation‡	Grain N Removal	Grain N-R2 §	N Ratio ¶
Russiaville		Total inorganic N (kg ha^{-1})								%
Manure	Low	107	54	-53	39	134	96	80	41	60
	Medium	139	73	-66	49	129	80	92	43	71
	High	159	107	-52	53	155	102	101	48	66
	UTC	59	41	-17	37	133	96	72	35	54
UAN	Low	101	67	-34	49	142	92	79	30	56
	Medium	190	150	-40	39	145	106	88	49	61
	High	322	175	-147	51	136	85	84	33	62
Farmersburg		Total inorganic N (kg ha^{-1})								%
Manure	Low	NT	186	na	60	161	102	119	59	74
	Medium	NT	201	na	74	193	119	121	47	63
	High	261	302	41	67	163	96	99	32	61
	UTC	43	43	1	41	172	130	130	89	76
UAN	Low	NT	69	na	57	193	136	137	80	71
	Medium	NT	114	na	53	171	118	131	78	77
	High	250	238	-12	68	196	128	130	62	67
Fort Branch		Total inorganic N (kg ha^{-1})								%
Manure	Low	69	63	-6	85	194	109	164	79	85
	Medium	127	63	-64	90	228	138	164	74	72
	High	152	76	-76	79	172	93	162	84	94
	UTC	49	51	2	58	221	162	154	95	70
UAN	Low	91	53	-38	75	203	128	163	88	80
	Medium	256	59	-198	72	204	132	161	89	79
	High	268	90	-179	86	243	157	170	84	70

NT = Not taken. Modified sampling was executed at Farmersburg at R2 due to soil and labor limitations.
Farmland data not included due to no R2 soil taken and an early freeze resulting in negligible yields
† Change in Soil N = post-harvest N minus R2 N
‡ Change in N Accumulation = R6 plant N accumulation minus R2 plant N accumulation
§ Grain N-R2 = Grain N removal minus R2 plant N accumulation
¶ N Ratio = (Grain N/R6 N accumulation)*100

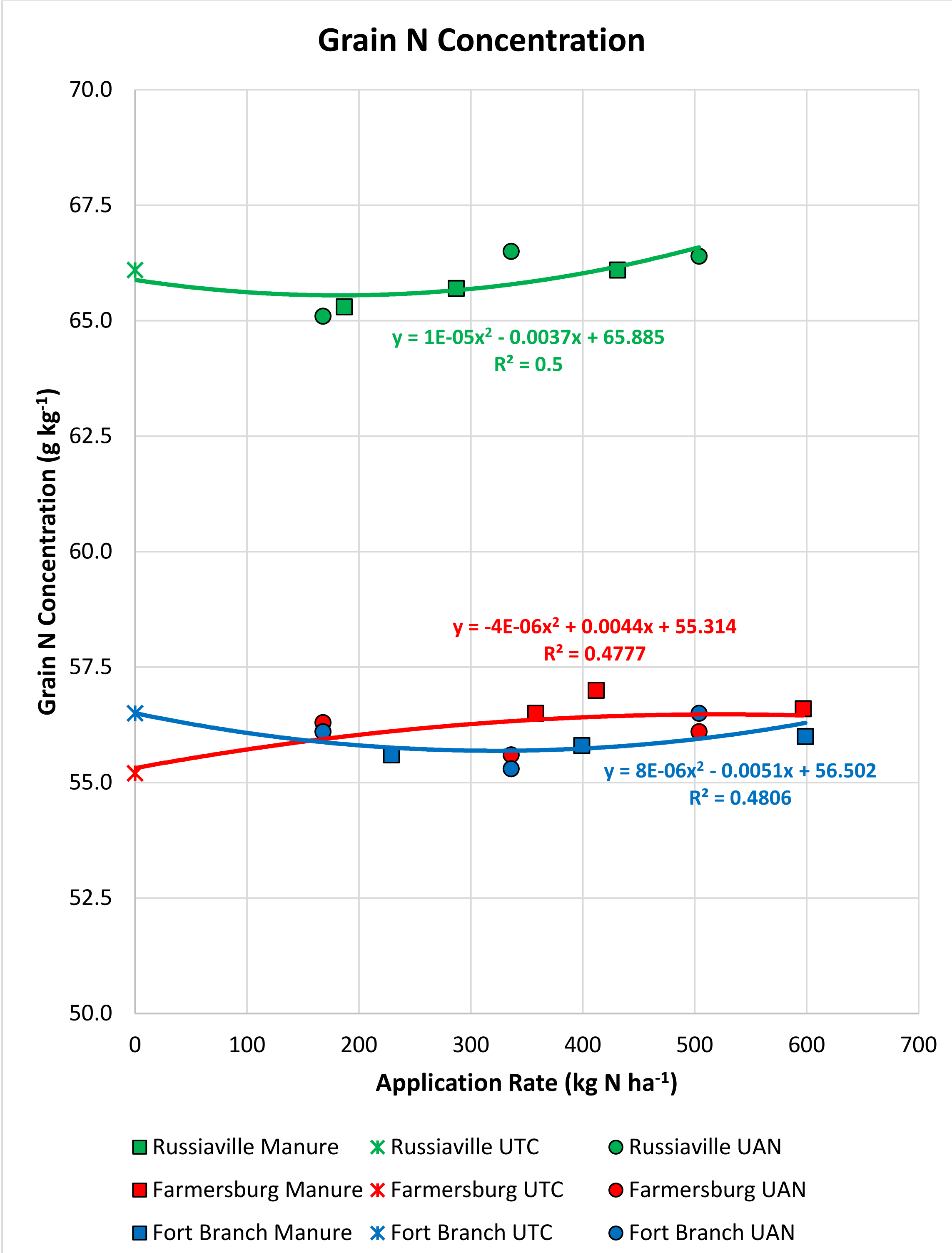

Figure A-1. Grain N concentration (g kg^{-1}) regressed against N application rate (kg N ha^{-1}) at Russiaville in 2012 and Farmersburg and Fort Branch in 2013.

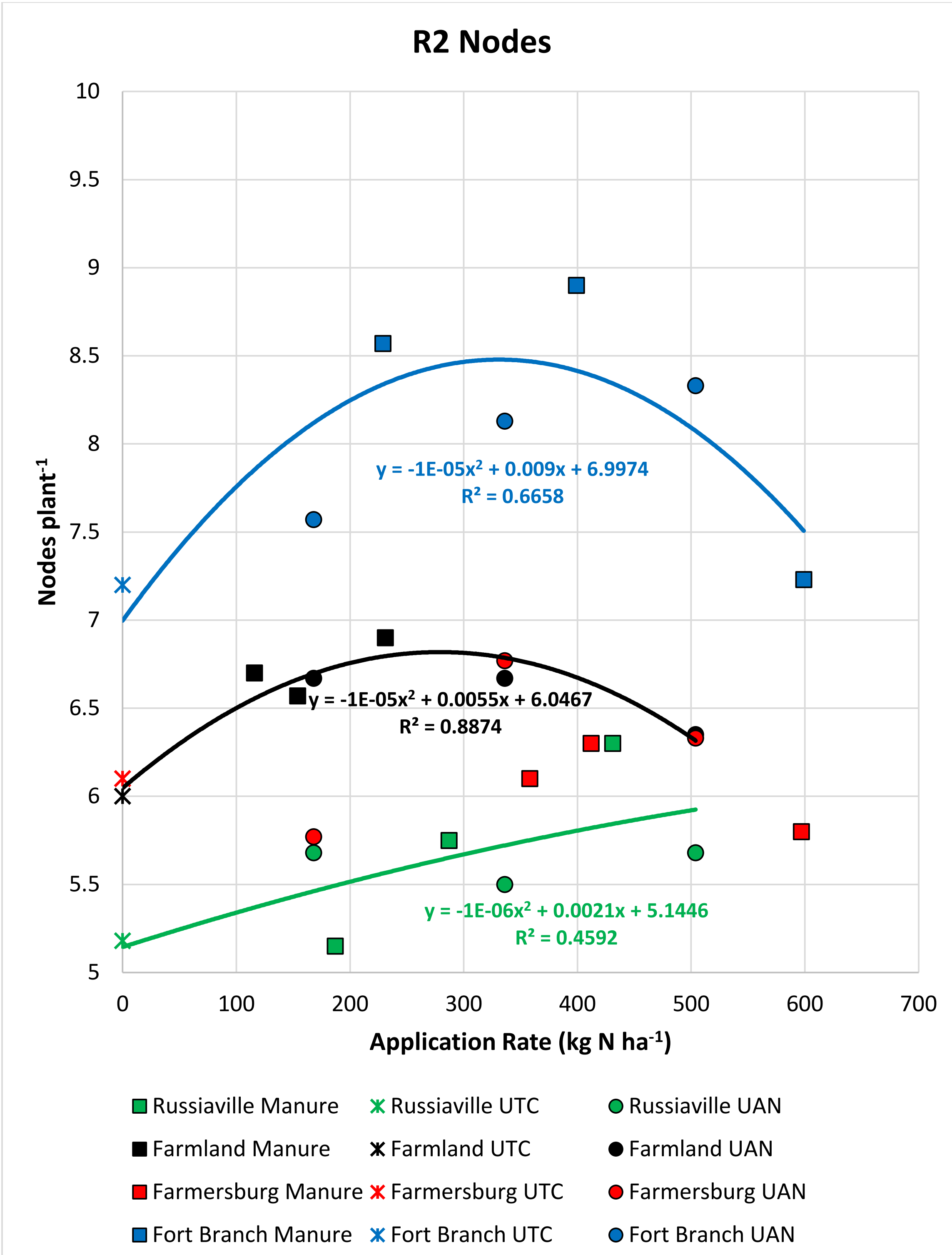

Figure A-2. Early season (R2) nodal development (nodes plant^{-1}) regressed against N application rate (kg N ha^{-1}) at Russiaville and Farmland in 2012 and Fort Branch in 2013. Farmersburg (2013) data not regressed, but presented.

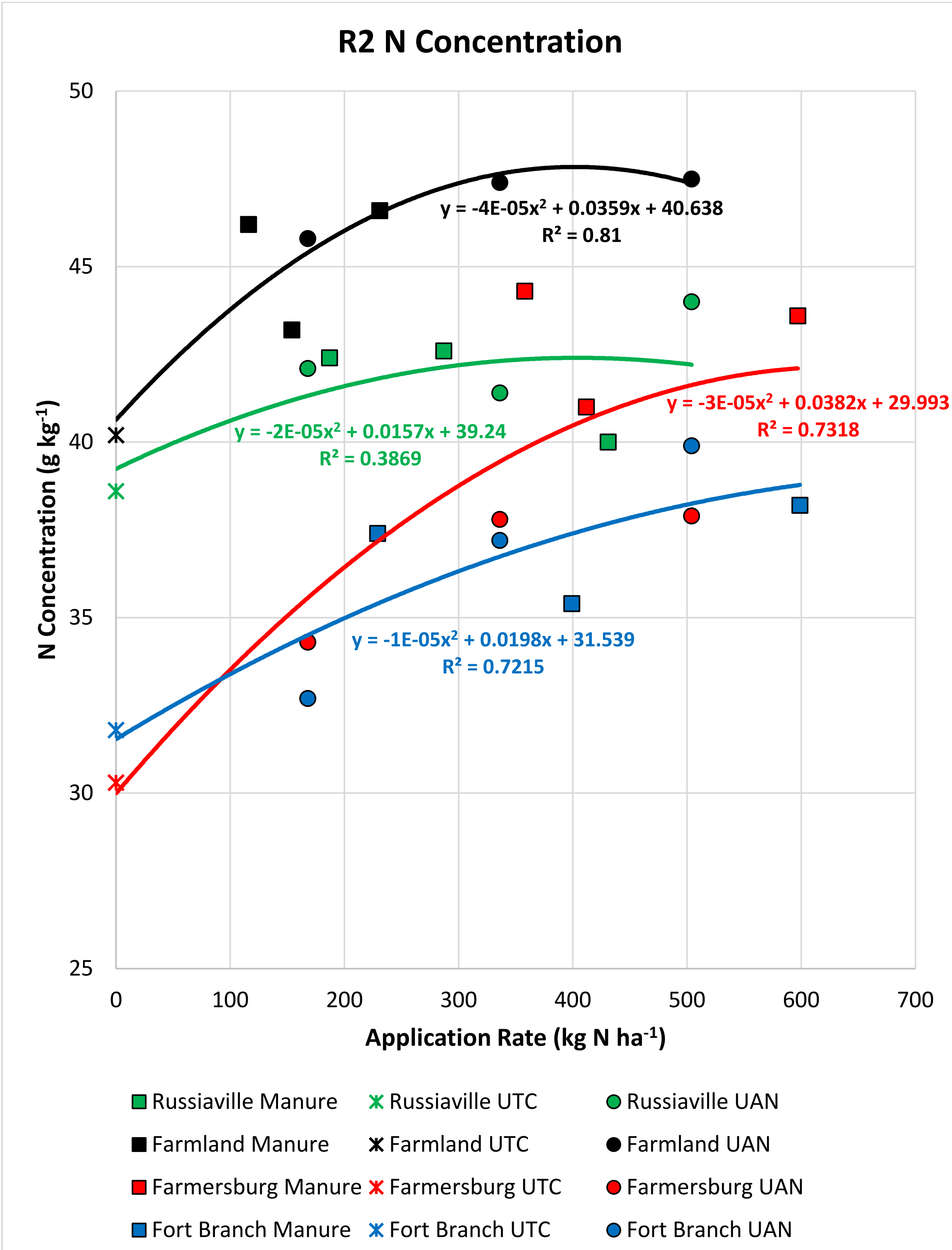

Figure A-3. Early season (R2) plant biomass N concentration (g kg^{-1}) regressed against N application rate (kg N ha^{-1}) at Russiaville and Farmland in 2012 and Farmersburg and Fort Branch in 2013.

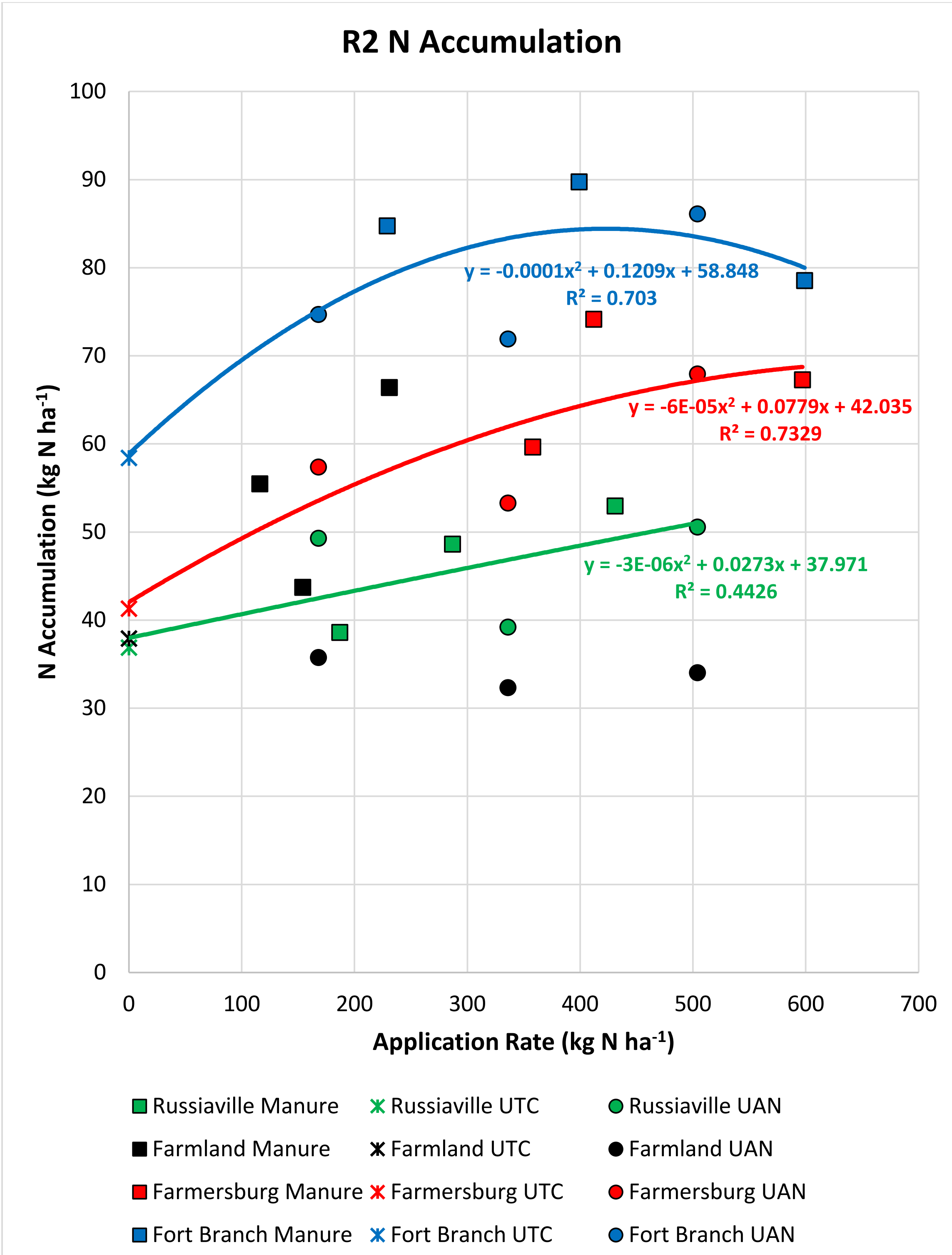

Figure A-4. Early season (R2) N accumulation in aboveground biomass (kg N ha^{-1}) regressed against N application rate (kg N ha^{-1}) at Russiaville in 2012 and Farmersburg and Fort Branch in 2013. Farmland (2012) data not regressed, but presented.

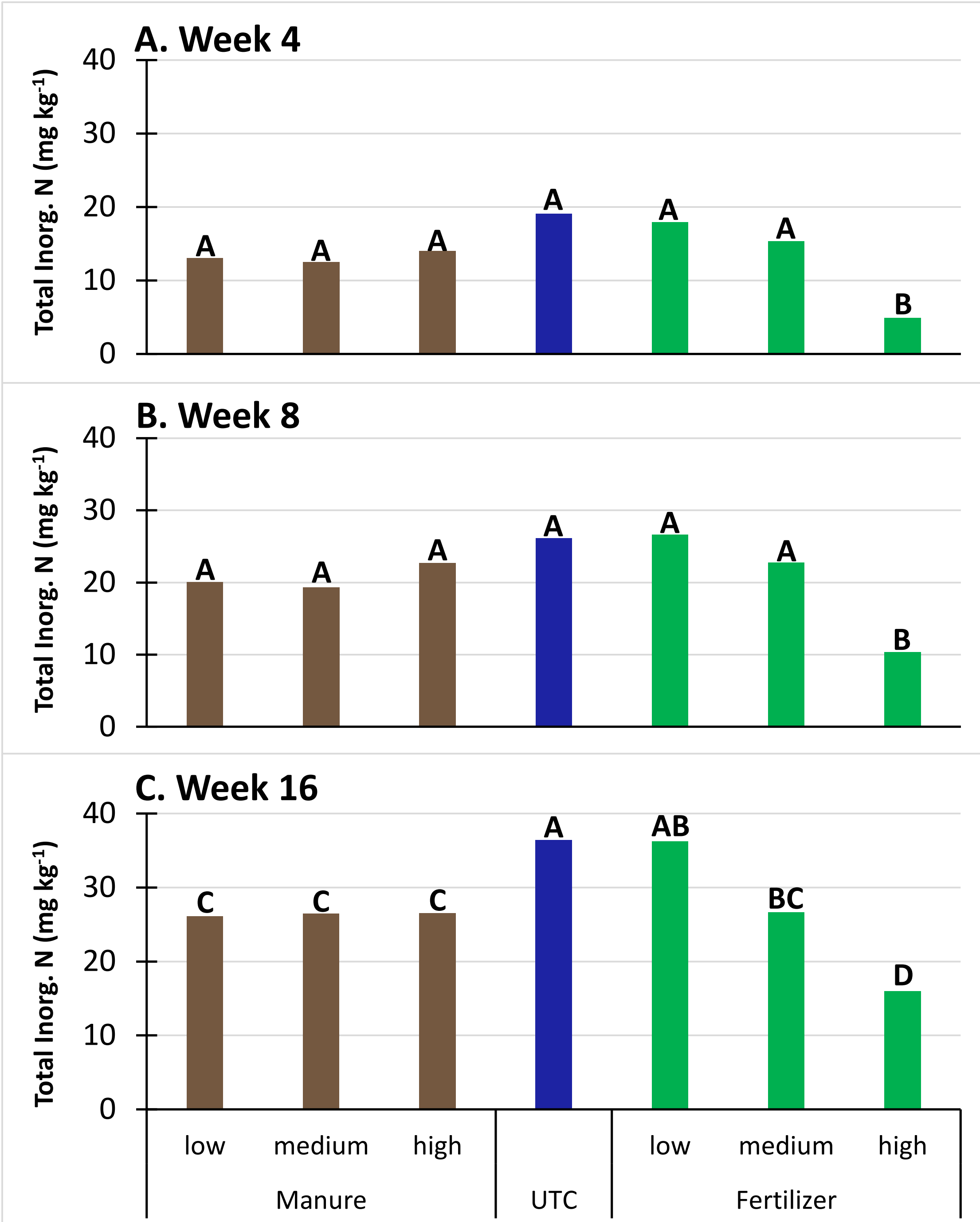

Figure A-5. Development of total inorganic nitrogen (NH_4-N + NO_3-N) after (A) four, (B) eight, and (C) sixteen weeks of incubation. Initial (wk 0) concentration of total inorganic nitrogen in each treatment has been subtracted. Soil amended with swine manure and fertilizer prior to planting double-crop soybean in Russiaville 2012. Field samples were taken from a soil depth of 0 to 30 cm when soybean was full bloom (~45 d after application). Treatments were separated within incubation period according to Fisher's Protected LSD.

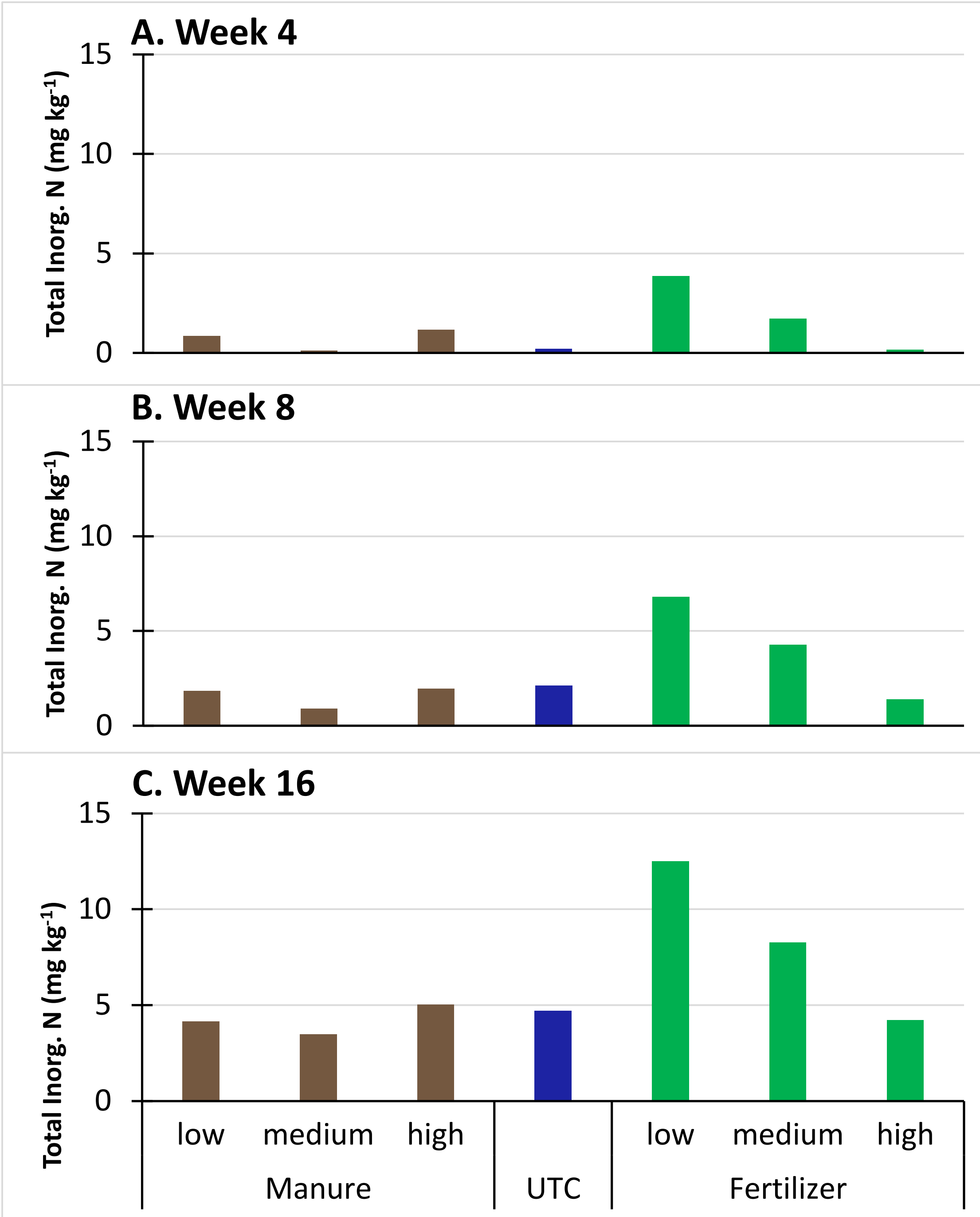

Figure A-6. Development of total inorganic nitrogen (NH_4-N + NO_3-N) after (A) four, (B) eight, and (C) sixteen weeks of incubation. Initial (wk 0) concentration of total inorganic nitrogen in each treatment has been subtracted. Soil amended with swine manure and fertilizer prior to planting double-crop soybean in Russiaville 2012. Field samples were taken from a soil depth of 30 to 60 cm when soybean was full bloom (~45 d after application). Treatments did not differ within incubation period.

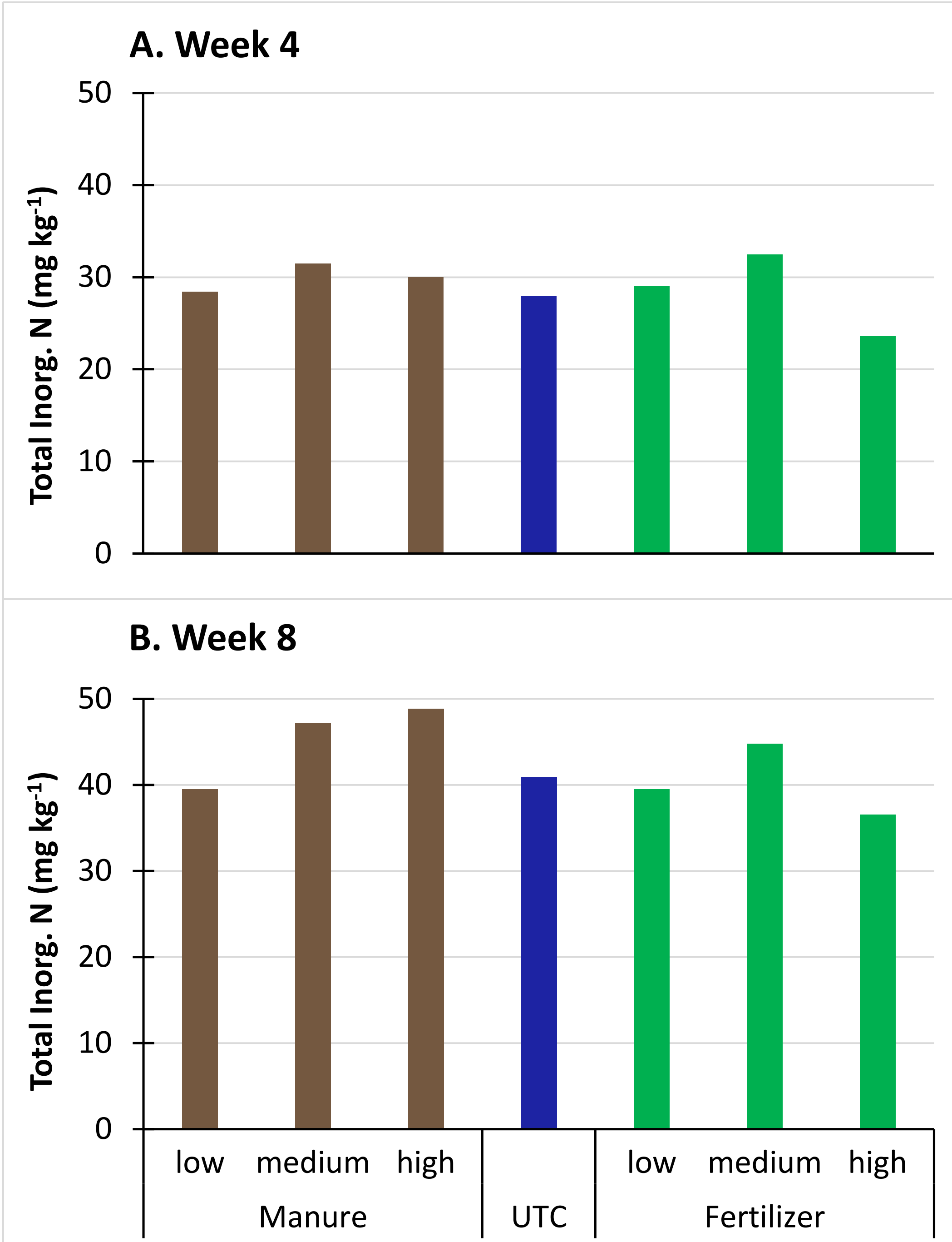

Figure A-7. Development of total inorganic nitrogen (NH_4-N + NO_3-N) after (A) four and (B) eight weeks of incubation. Initial (wk 0) concentration of total inorganic nitrogen in each treatment has been subtracted. Soil amended with swine manure and fertilizer prior to planting double-crop soybean in Fort Branch 2013. Field samples were taken from a soil depth of 0 to 30 cm when soybean was full bloom (~45 d after application). Treatments did not differ within incubation period.

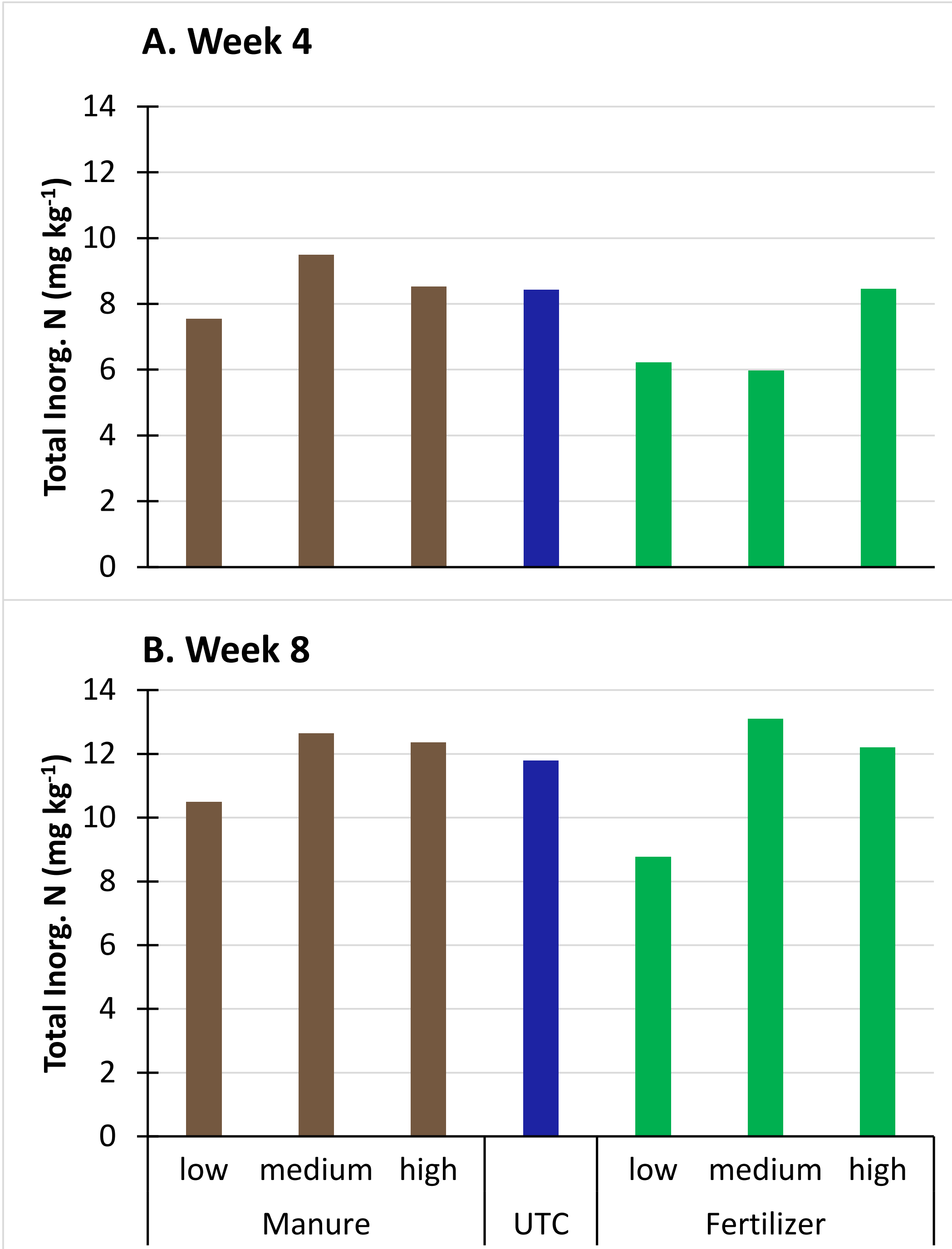

Figure A-8. Development of total inorganic nitrogen (NH_4-N + NO_3-N) after (A) four and (B) eight weeks of incubation. Initial (wk 0) concentration of total inorganic nitrogen in each treatment has been subtracted. Soil amended with swine manure and fertilizer prior to planting double-crop soybean in Fort Branch 2013. Field samples were taken from a soil depth of 30 to 60 cm when soybean was full bloom (~45 d after application). Treatments did not differ within incubation period.

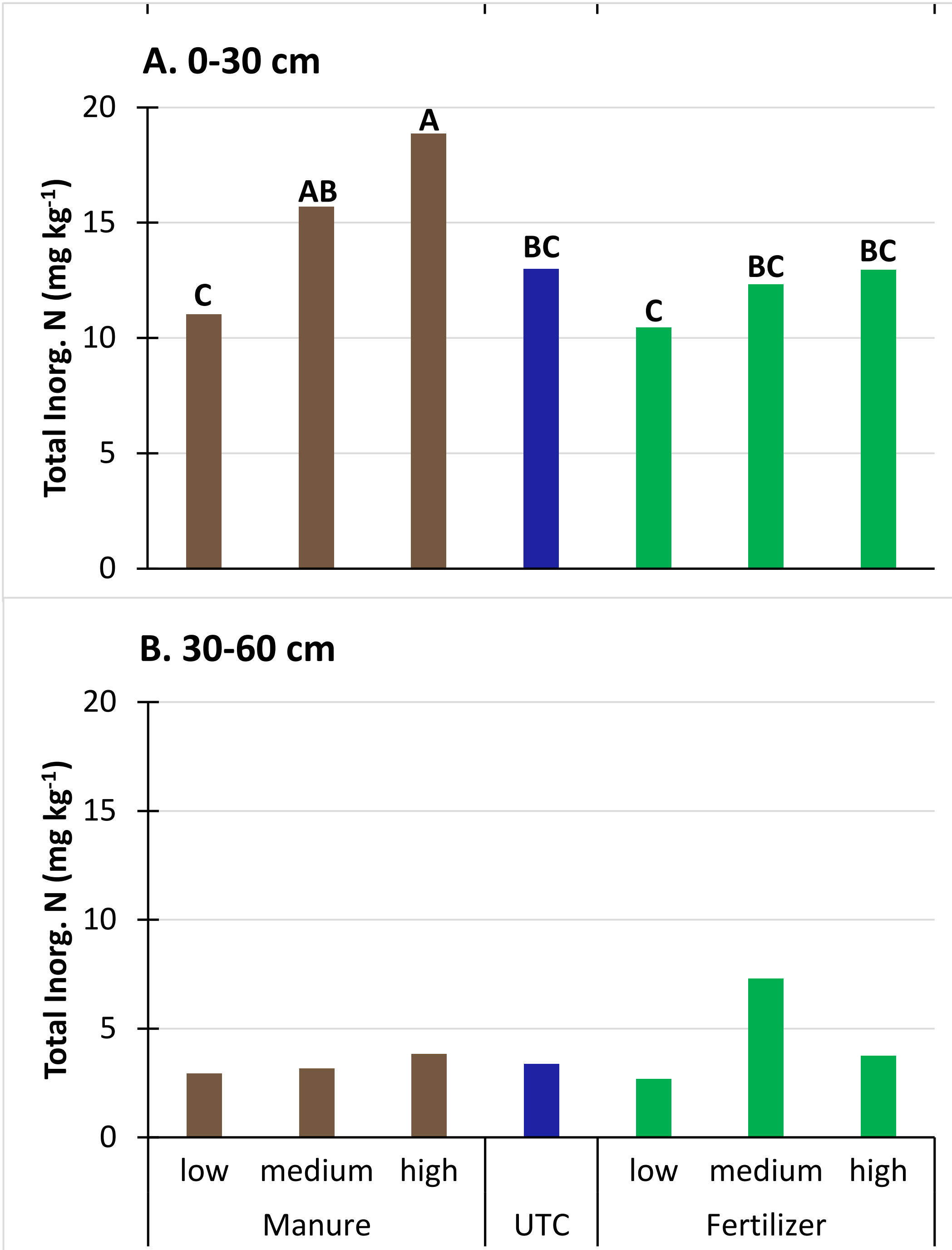

Figure A-9. Development of total inorganic nitrogen (NH_4-N + NO_3-N) at (A) 0 to 30 cm and (B) 30 to 60 cm. Week four concentration of total inorganic nitrogen in each treatment has been subtracted from week eight. Soil amended with swine manure and fertilizer prior to planting double-crop soybean in Fort Branch 2013. Field samples were taken when soybean was full bloom (~45 d after application). Treatments were separated within depth at 0 to 30 cm according to Fisher's Protected LSD. Treatments did not differ within depth at 30 to 60 cm.

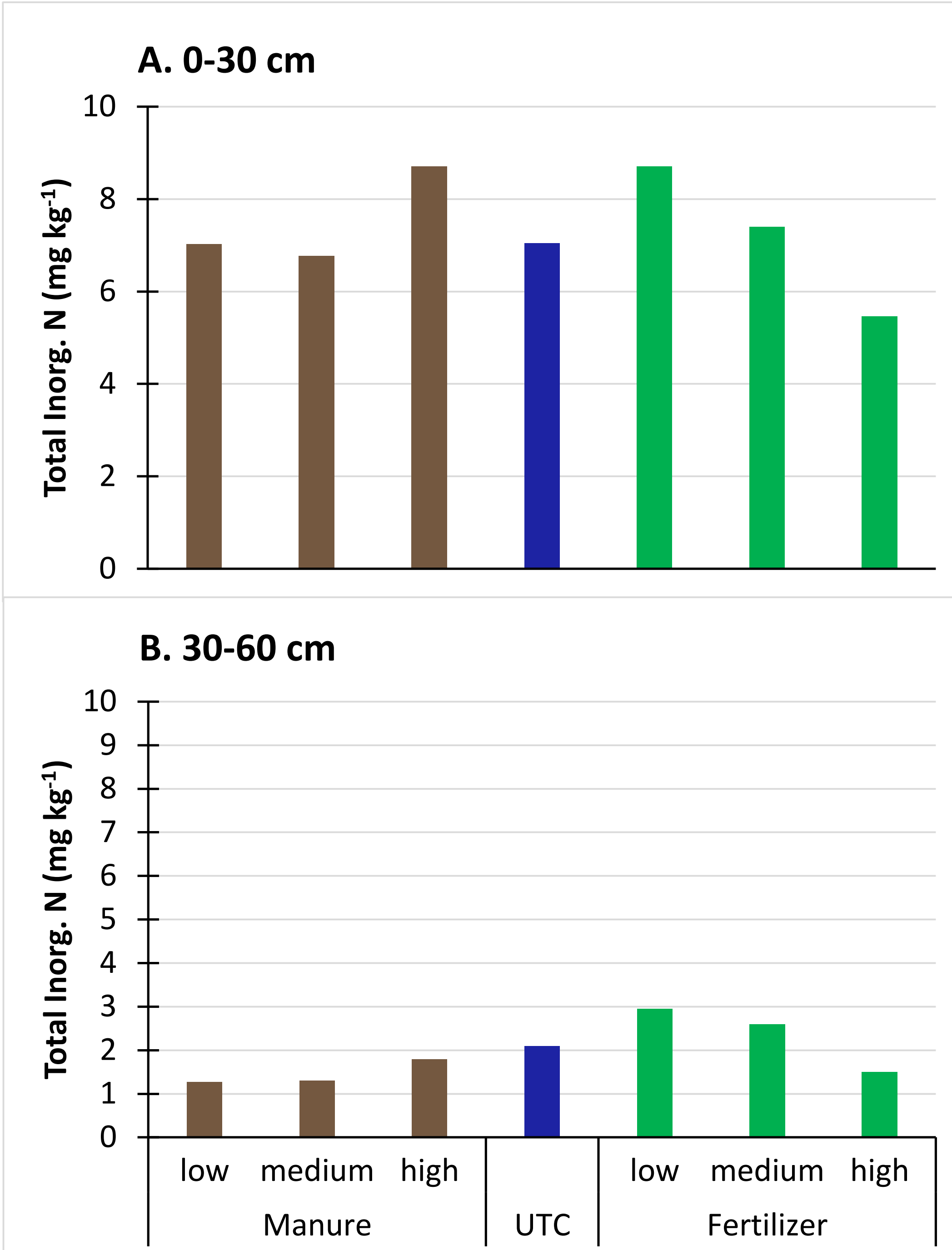

Figure A-10. Development of total inorganic nitrogen (NH_4-N + NO_3-N) at (A) 0 to 30 cm and (B) 30 to 60 cm. Week four concentration of total inorganic nitrogen in each treatment has been subtracted from week eight. Soil amended with swine manure and fertilizer prior to planting double-crop soybean in Russiaville 2012. Field samples were taken when soybean was full bloom (~45 d after application). Treatments did not differ within depths.